# NAVAL POSTGRADUATE SCHOOL
## Monterey, California



# THESIS

**A SYSTEM DYNAMICS BASED STUDY OF SOFTWARE REUSE AND ITS DETERMINANTS**

by

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September, 1994

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| REPORT DOCUMENTATION PAGE | Form Approved OMB No. 0704 |
|---|---|



| 1. AGENCY USE ONLY *(Leave blank)* | 2. REPORT DATE September 1994 | 3. REPORT TYPE AND DATES COVERED Master's Thesis, Final |
|---|---|---|

| | |
|---|---|
| 4. TITLE AND SUBTITLE A System Dynamics Based Study of Software Reuse and Its Determinants | 5. FUNDING NUMBERS |
| 6. AUTHOR(S) Wayne L. Aiken | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000 | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER |

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

| | |
|---|---|
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited | 12b. DISTRIBUTION CODE A |

13. ABSTRACT *(maximum 200 words)*

Software cost for DoD is a critical issue. Software reuse promises significant cost savings by using previously developed components thus increasing productivity. Quality is improved because these components are well designed, well documented, and well tested. This thesis studies the determinants of software reuse using a system dynamics computer model, the Dynamcia Reuse Model, which simulates the activities of a software development organization engaged in organization-wide, systematic software reuse. Results indicate that setting goals of consumption and production of components too low will lead to a decreased reuse rate. In the area of consumption and production costs of reusable components, production costs are more critical. Regarding employee turnover, reuse is enhanced by a low rate of turnover of personnel. In establishing a successful reuse program, creating a repository is an important factor and the study indicates there is a structurally stable repository value. Concerning the software development rate of components, a steady development rate leads to a more consistent reuse rate. DoD managers can now use these results in formulating policies concerning their systematic reuse program.

| | |
|---|---|
| 14. SUBJECT TERMS Software Reuse Determinants, Software Development, Dynamica Reuse Model | 15. NUMBER OF PAGES 87 |
| | 16. PRICE CODE |

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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**A System Dynamics Based Study of Software Reuse and Its Determinants**

by

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
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Software cost for DoD is a critical issue. Software reuse promises significant cost savings by using previously developed components thus increasing productivity. Quality is improved because these components are well designed, well documented, and well tested. This thesis studies the determinants of software reuse using a system dynamics computer model, the Dynamica Reuse Model, which simulates the activities of a software development organization engaged in organization-wide, systematic software reuse. Results indicate that setting goals of consumption and production of components too low will lead to a decreased reuse rate. In the area of consumption and production costs of reusable components, production costs are more critical. Regarding employee turnover, reuse is enhanced by a low rate of turnover of personnel. In establishing a successful reuse program, creating a repository is an important factor and the study indicates there is a structurally stable repository value. Concerning the software development rate of components, a steady development rate leads to a more consistent reuse rate. DoD managers can now use these results in formulating policies concerning their systematic software reuse program.

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# I. INTRODUCTION

## A. SOFTWARE REUSE DEFINED

Software reuse is considered one answer to the software crisis of increased costs, delayed schedules, unsatisfied requirements and software professional shortages (Kim and Stohr, 1992). Software reuse is the utilization of previously compiled information or knowledge (Williams, 1991), and applies to every product of the software development process including software architectures, requirements, designs, code, test plans, and tools (Schimsky, 1992). The major advantage of software reuse is reduction in or elimination of development of these items thus increasing productivity (Williams, 1991). Software reuse also contributes to quality because reusable components are well designed, well documented, and well tested (Tracz, 1987).

## B. DOD SOFTWARE REUSE REVIEWED

The problem in software development is not lack of reuse but a lack of institutionalized reuse. Programmers have always been reusing code, subroutines, and algorithms. However, the substantial quality and productivity payoffs come only if reuse is practiced systematically and formally (Prieto-Diaz, 1993). In 1991, DoD started such a program with the Defense Software Reuse Initiative. The basic thrust was to identify reuse opportunities and establish processes to

capitalize on those opportunities. The initiative was a voluntary and cooperative alliance of individual DoD reuse activities (GAO, 1993).

The Defense Software Reuse Initiative did not totally achieve its objective and DoD is now reorganizing its software reuse program into the Strategic Reuse Initiative (SRI). SRI places the reuse program under a single manager and removes the voluntary alliance. The goals of the SRI program are (Endoso, 1994):

- Bring reuse technology into the DoD mainstream.
- Develop an infrastructure that reduces the cost and risk of adopting and sustaining reuse.
- Encourage, reward and institutionalize effective software reuse.

The Assistant Secretary of Defense for Command, Control, Communications and Intelligence has indicated effective software reuse can result in large savings in DoD's estimated 1995 software budget of $42 billion. "The commercial sector has shown that reuse can reduce overall software expenses by between 10 percent and 15 percent and cut maintenance costs by 20 percent" (Endoso, 1994).

Organization wide software reuse is not easy to implement. There are significant technical, organizational, and legal barriers for DoD to overcome in order to implement effective software reuse (GAO, 1993). In order to establish informed policy decisions, DoD managers need a systematic process or tool that gives insight into what determinants will effect the rate of software reuse. A model that uses system dynamics and integrates the various complex relationships of an organization practicing software reuse provides for such a tool.

## C. THESIS OBJECTIVE

This thesis will study the effects on software reuse of various management policies and technical factors. Specifically, the following areas will be studied to determine the effects on software reuse:

- what are the effects of management goals of reuse consumption and production rates?
- what are the effects of relative productivities of consumption and production?
- what are the effects of employee turnover?
- what are the effects of repository size?
- what are the effects of varying the software development rate?

## D. METHODOLOGY

The methodology will consist of running simulations of various management policy decisions using the Dynamica Reuse Model. The simulations will be analyzed to determine the effect of the various decisions on long-term software reuse. The next chapter will provide an overview of software reuse and introduce the determinants that effect software reuse. This will facilitate understanding of the Dynamica Reuse Model that will be described in Chapter III. Chapter IV will provide the results of the simulation runs and conclusions will be presented in Chapter V.

## II. LITERATURE REVIEW

### A. OVERVIEW

Introduction of reuse into an organization and the associated modification to the personnel and practices of the organization is a complex, interdisciplinary task (Wasmund, 1993). Success has been achieved in organizations which supported, promoted, and maintained systematic reuse (Prieto-Diaz, 1991).

The software reuse process has three distinct phases: reusable component production, reusable component management or storage, and component consumption (GAO, 1993). Software reuse can be approached as an ad-hoc, opportunistic process or as a very deliberate, systematic process. The ad-hoc approach is analogous to "scavenging" for the reusable component. The component is recognized during the requirements/design phase of a project and used specifically for that project. This approach does not lend itself to a general application of software reuse. In systematic reuse, an organized effort is done to analyze the need, potential application, and payoff of software reuse components. Systematic reuse also includes management of a library of those components (Schimsky, 1992). In systematic reuse, new reusable software is continuously created as a byproduct of applications development to replenish the organization repository (GAO, 1993).

Issues dealing with software reuse are generally divided into two broad classes; managerial and technical. Managerial issues deal with top-level support for reuse, organizational behavior, contractual and legal considerations, financial incentives, and reuse metrics (Hooper and Chester, 1991). Technical issues are concerned with domain analysis, classification of software components, interoperabilty of software repositories, adaptation of software components, and reuse of systems designs and architectures (GAO, 1993).

Comprehensive studies of several of these issues have previously been published, e.g., reuse engineering (Palmer and Cohen, 1990; Gall and Klosch, 1992), reuse metrics (Reifer, 1990; Tirso, 1991), methodologies of reuse (Kang and Levy, 1989), and legal aspects (Schimsky, 1992). This thesis will evaluate a set of organizational determinants of successful reuse, discussed in the next section.

## B. DETERMINANTS OF SOFTWARE REUSE

### 1. Consumption and Production Goals

Experience has shown that successful reuse is one where there is management commitment to make reuse work by fostering a climate where good practices are rewarded (Biggerstaff and Perlis, 1989). This means more than simply issuing directives to implement reuse. It means providing the necessary resources to bring about a different way of approaching software development and maintenance (Hooper and Chester, 1991). An important point for

management is to take the long-term view. The reuse life-cycle is significantly longer that the life-cycle of normal components (Wolff, 1992).

Management needs to understand the psychological tendency to not reuse because of the difficulty of integrating the components into real applications (Favaro, 1991). Organizations that have been successful in software reuse have installed incentives to encourage reuse. For example, some organizations have instituted a royalty type scheme that encourages consumption by offering payment to a component "author" each time a reusable component is consumed (Kim and Stohr, 1992).

There is a paradox in establishing management policies for production of reusable components. The process of producing these components benefits the organization but yet is an excess cost to employees producing components and may in fact delay their immediate project (Hooper and Chester, 1991; Bollinger and Pfleeger, 1990). However, management should support the production of components with reuse in mind. Modifying the components for reuse at a later time is expensive (Incorvaia, 1990).

### 2. Relative Productivities of Consumption and Production

Software reuse has as its premise that reusable code should cost less than new components. Nevertheless, there is some cost associated with consuming the component. Adaptation cost involves modifying a component to

make it reusable. Adaptation is a difficult process because the consumer must understand how the component functions (GAO, 1993).

Software reuse consumption has two categories: horizontal and vertical. Horizontal reuse crosses a wide range of application areas. Vertical reuse refers to components within the same problem domain. Horizontal reuse is easier to understand and to implement. However, vertical reuse offers the greatest potential leverage (Hooper and Chester, 1991).

Conversely, reusable components are more expensive to produce because of the additional effort to generalize and test the component, to document the component, and to classify and retain the component in a repository for later reuse (Hooper and Chester, 1991). Economics of software reuse dictate that a reusable component be reused enough times to cover this additional development cost (Bollinger and Pfleeger, 1990).

The benefit of the reusable component to the organization is the cost avoided by not having to develop that component (Schimsky, 1992). Management should encourage production of reusable components by using tools such as models to make informed decisions including "make versus reuse versus buy" decisions (Hooper and Chester, 1991).

### 3. Employee Turnover

Employees of a software reuse organization are important in the reuse process. Management should support them with the fullest and best resources,

e.g., workstations, tools, environments, and offices (Biggerstaff and Perlis, 1989). In addition, management can encourage software reuse by providing corporate-level support for reuse, defining carefully reuse roles for all personnel involved, etc. (Hooper and Chester, 1991). Along with financial incentives to encourage reuse, training in software reuse can not be overlooked. For example, at one software manufacturing facility, a Japanese company has incorporated software reuse as part of the training program for all its programmers (Tracz, 1987).

**4. Repository Size**

A fully stocked library or repository of reusable components and all the services that a library normally provides must exist (Schmisky, 1992). A quality repository goes beyond storage of components and serves as a clearinghouse for effective reuse. Activities of a clearinghouse include defining reuse, searching for components, certifying components, creating a user-friendly library, and supporting the users (Bui, et al., 1993).

Tools and methodologies will be needed to support developing and cataloging reusable components and composing software systems from them (Tracz, 1987). The faceted classification system that is based on library science is one such method (Prieto-Diaz and Freeman, 1987). Large organizations, such as DoD may need to have a network of software libraries with nodes at the various sites conducting software reuse (Schimsky, 1992). However, the

relationship between the number of components in a library and reuse of those components is not linear. Increasing the size of the pool of components will not lead to increased reuse (Banker, et al., 1993).

### 5. Software Development Rate

Software development rate concerns the total absolute amount of software that an organization produces. Software development rate can be relatively stable over time or it may change, i.e., increase or decrease. It is typically driven by factors external to the software development group such as the growth of the overall organization. However, this rate of growth can greatly affect the software development process because it affects the stability of the workforce. For example, unstable workforce level will have lower fraction of experienced staff, which can affect reuse rate (Abdel-Hamid, 1994).

## C. NEED FOR ANALYTICAL TOOLS

Each of these issues concerning software reuse is complex and managers need an instrument to study the process in order to make informed decisions. The dilemma for managers is that these very tools needed to support a reuse process are lacking (GAO, 1993). For example, there is a need to develop economic models of software reuse which consider software development as a component of reuse (Kim and Stohr, 1992). The next chapter will provide a summary of current models and provide a background of a more comprehensive model that uses systems dynamics, the Dynamica Reuse Model.

# III. MODELING OF SOFTWARE REUSE

## A. CURRENT MODELS

There are numerous models covering the various aspects of the software reuse process. Literature delineating the models has previously been published, e.g.; economic models (Gaffney and Cruickshank, 1992; Margono and Rhoads, 1992;); reuse process (Durin, et al., 1990); and reuse strategies (Matsumura, et al., 1990). Each model provides an analysis of an individual area of software reuse but fails to provide a comprehensive study of the entire reuse process. By integrating the components of the software reuse process, the Dynamica Reuse Model provides a total system viewpoint and allows for studying the complex set of interactions and trade-offs that characterize software reuse (Abdel-Hamid, 1993).

## B. SYSTEM DYNAMICS

The Dynamica Reuse Model is based on the concept of system dynamics. "System dynamics is the application of feedback control systems principles and techniques to managerial, organizational, and socioeconomic problems." System dynamics is founded on the belief that behavior of an organization is principally determined by the organization's structure. Organizations can therefore be viewed in terms of their flows and the cause-and-effect changes which can be traced through these flows (Roberts, 1978).

These organizational relationships are of two categories: levels and rates. A level represents accumulations of resources. A rate includes activities of the system such as flows, decisions, or actions that change over time as a function of the influences acting upon it. Once the organizational relationships are represented in levels and rates, system dynamics then applies computer simulation techniques. These techniques enable the user to understand the complex interrelationships of the system (Roberts, 1978).

## C. THE DYNAMICA REUSE MODEL

The model used in this thesis, the Dynamica Reuse Model, proposes a completely different approach to analyzing software reuse. The Dynamica Reuse Model is a computer program that simulates a software development organization that practices organization-wide software reuse. (Abdel-Hamid, 1993)

The model has three important characteristics that differentiate it from other software reuse models. First, the model <u>integrates</u> both the technical issues such as reusable component production, classification, storage, identification, and consumption, and the managerial issues such as setting reuse production and consumption policy and goals. Second, the model uses the <u>feedback</u> principles of system dynamics to better understand the complex system of organizational software reuse. "Circular feedback processes are universal in social systems, the software engineering domain being no exception." Third, the model uses computer <u>simulation</u> to handle over 200 difference equations

integrating hundreds of variables relating to technical and managerial issues in organization-wide software reuse. Computer simulation provides for controlled experimentation (Abdel-Hamid, 1993).

The model is composed of five major sectors. Each one of these sectors interacts with each of the other sectors. The software development and maintenance sector defines the overall organizational setting. It provides broad policy on software production for the entire organization, such as the project portfolio size, the average project size, software type, and the maintenance backlog (Abdel-Hamid, 1993).

The reusable component production sector models software reuse activities relating to the production of reusable components, such as domain analysis and the "degree of functional overlap between applications in the domain." Elements associated with production include reuse support, learning, schedule pressures, perceived cost, and organizational goals (Abdel-Hamid, 1993).

The reusable component consumption sector models software reuse activities associated with consumption. These factors include perceived benefits of reuse, repository size, reuse support, learning, overlap between applications, and schedule pressure (Abdel-Hamid, 1993).

The human resource sector models the size and characteristics of the organization's personnel and is affected by activities such as the hiring and firing of

staff, allocating staff resources, training of the personnel, and turnover (Abdel-Hamid, 1993).

The management policy sector models the interventions of setting reuse goals, allocating resources, and defining the organization. These interventions are management's leverage points to affect the software reuse process in the organization (Abdel-Hamid, 1993).

# IV. DYNAMICA REUSE MODEL SIMULATION RESULTS

## A. INTRODUCTION

All computer simulations presented here were conducted using the Dynamica Reuse Model described in Chapter III. The simulations used the Reuse6 version of the model. Appendix A presents a complete list of the variables used and provides definitions of all variables described in this chapter. The model allows a selection of time duration and all simulations used either ten years, twenty years, or thirty years. All graphs presented in the chapter depict time along the x-axis in months. Appendices B - F list the Dynamica Reuse Model tabular data for all graphs. Data in appendices are presented in yearly increments.

The following sections present the simulation results for the following determinants of software reuse: **Consumption and Production Goals, Relative Productivities of Consumption and Production, Employee Turnover, Repository Size, Software Development Rate.**

## B. CONSUMPTION AND PRODUCTION GOALS

The Dynamica Reuse Model was used to determine the effect of setting higher and lower consumption and production goals on *Reuse Rate*. In order to study the effect of establishing these goals, two model switches were used to keep the goals "artificially" stable throughout the simulation runs, i.e., rather than have the goals dynamically increase or erode. For the consumption goal, the

switch STRUGL was used. For the production goal, the switch STPRGL was used.

*Reuse Rate* is calculated as $\frac{\textit{components reused}}{\textit{reused} + \textit{new components}}$. *Production Rate* is defined as the number of reusable components produced as a percentage of total number of components delivered. Another measure of production, included in Appendix A and graphically represented in later sections, is the *Adjusted Production Rate* which takes into account only newly produced components, i.e., excludes the number of reused components in calculating the denominator. The two production rates are the same only when *Reuse Rate* is zero. For example, given the two production scenarios described in Figure 1, *Production Rate* for both is .5 but *Adjusted Production Rate* is .5 for Company X and .625 for Company Y.

| | Company X | Company Y |
|---|---|---|
| | 100 Components Delivered of which: | 100 Components Delivered of which: |
| Reused: | 0 | 20 |
| New: | 100 | 80 |
| Developed for Reuse: | 50 of 100 | 50 of 100 |
| Reusable *Production Rate*: | 50/100 =.5 | 50/100=.5 |
| *Adjusted Production Rate*: | 50/100=.5 | 50/80=.625 |

**Figure 1: Comparison of *Production Rate* and *Adjusted Production Rate***

*Reuse Goal* is the organization's goal for *Reuse Rate*. *Production Goal* is the reusable component production goal.

In the first simulation run, *Reuse Goal* was set at 15%, the nominal case. In the second simulation run, *Reuse Goal* was lowered to 5%. In the third simulation run, *Reuse Goal* was raised to 30%. Figure 2 shows the three resulting *Reuse Rates* and Figure 3 shows the three resulting *Production Rates*. The results indicate that a lower *Reuse Goal* leads to lower consumption and production rates. On the other hand, consumption and production did not change when the goal was raised.

Next, the effects of higher and lower goals of production on *Reuse Rate* were studied. The first simulation run established a *Production Goal* of 10%, the nominal case. For the second run, *Production Goal* was lowered to 5%. For the third run, *Production Goal* was raised to 20%. Figure 4 shows the three *Reuse Rates* and Figure 5 shows the three *Production Rates*. Once again, the lower goal results in lower *Reuse Rates* and *Production Rates*. Consumption and production did not change when the goal was raised.

## C. RELATIVE PRODUCTIVITIES OF CONSUMPTION AND PRODUCTION

The Dynamica Reuse Model was used to determine the effect of varying the relative productivities of consumption and production on *Reuse Rates*. *Consumption Cost* is the relative cost of reusing a component. A value of 1 means that it is the same relative cost as the cost of developing an all-new component.

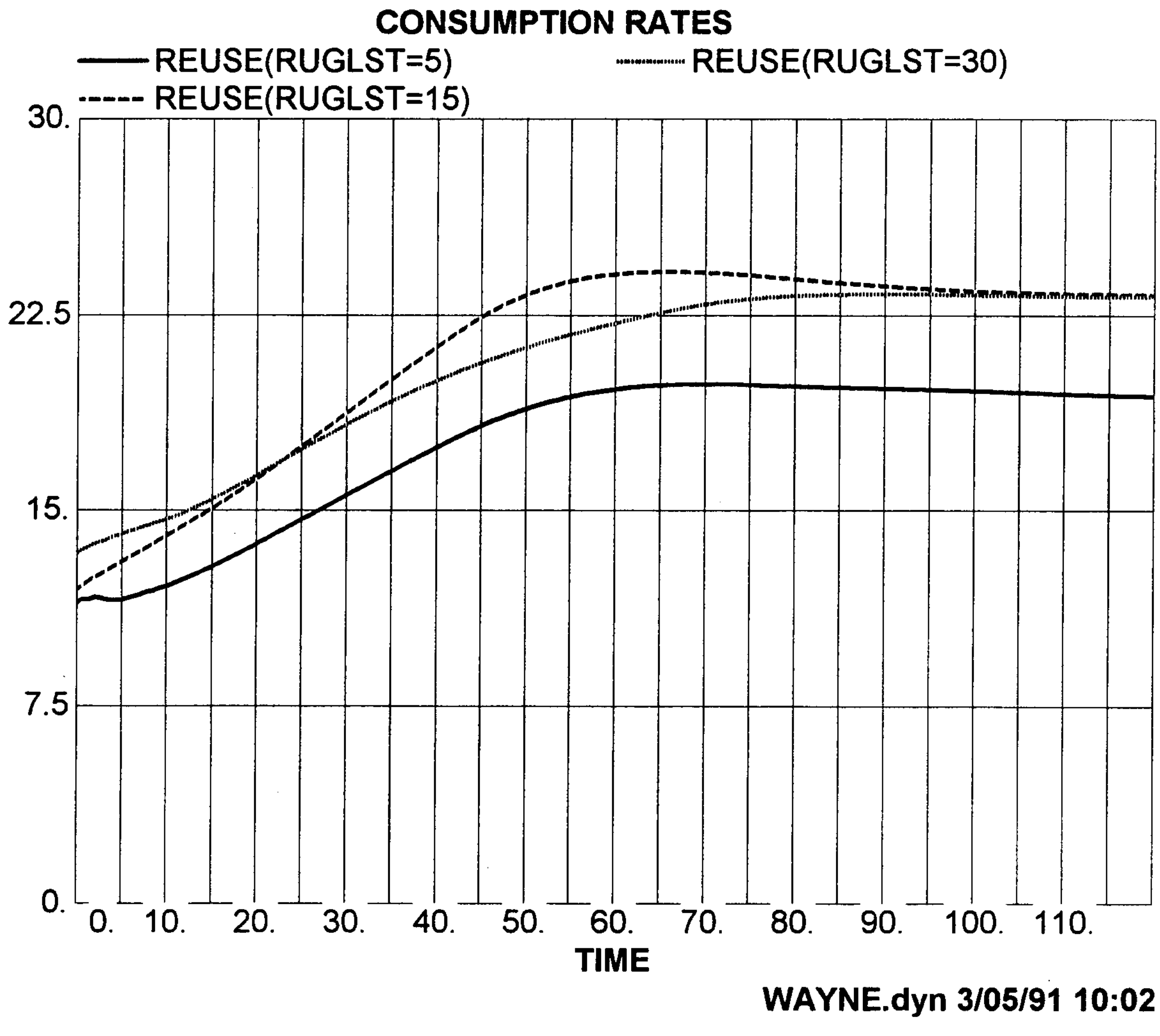


**Figure 2: Impact of Consumption Goal on *Reuse Rate***
**(*Reuse Goal* = 5, 15, 30 STRUGL = 0)**

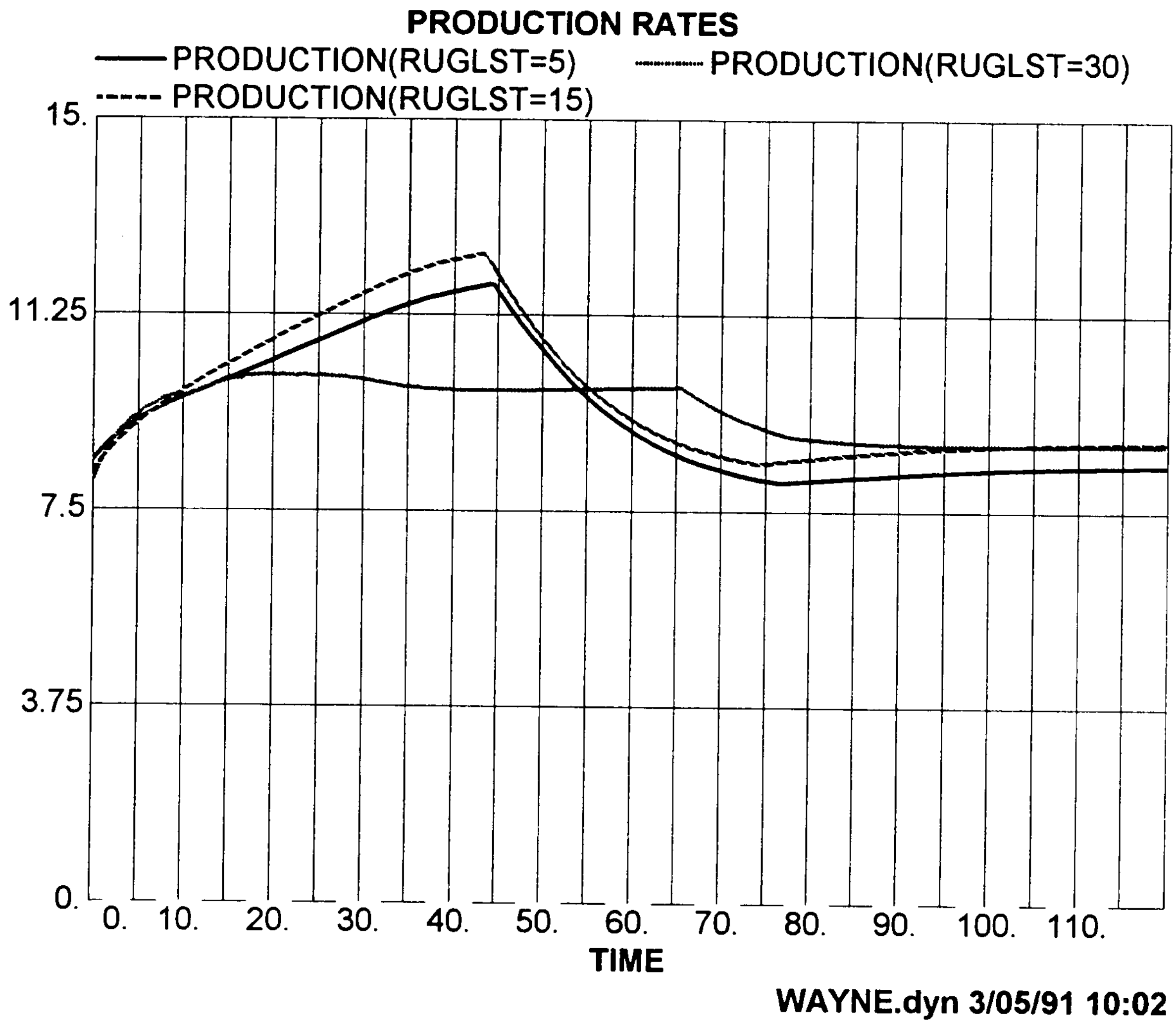


**Figure 3: Impact of Consumption Goal on *Production Rate* (*Reuse Goal* = 5, 15, 30 STRUGL = 0)**

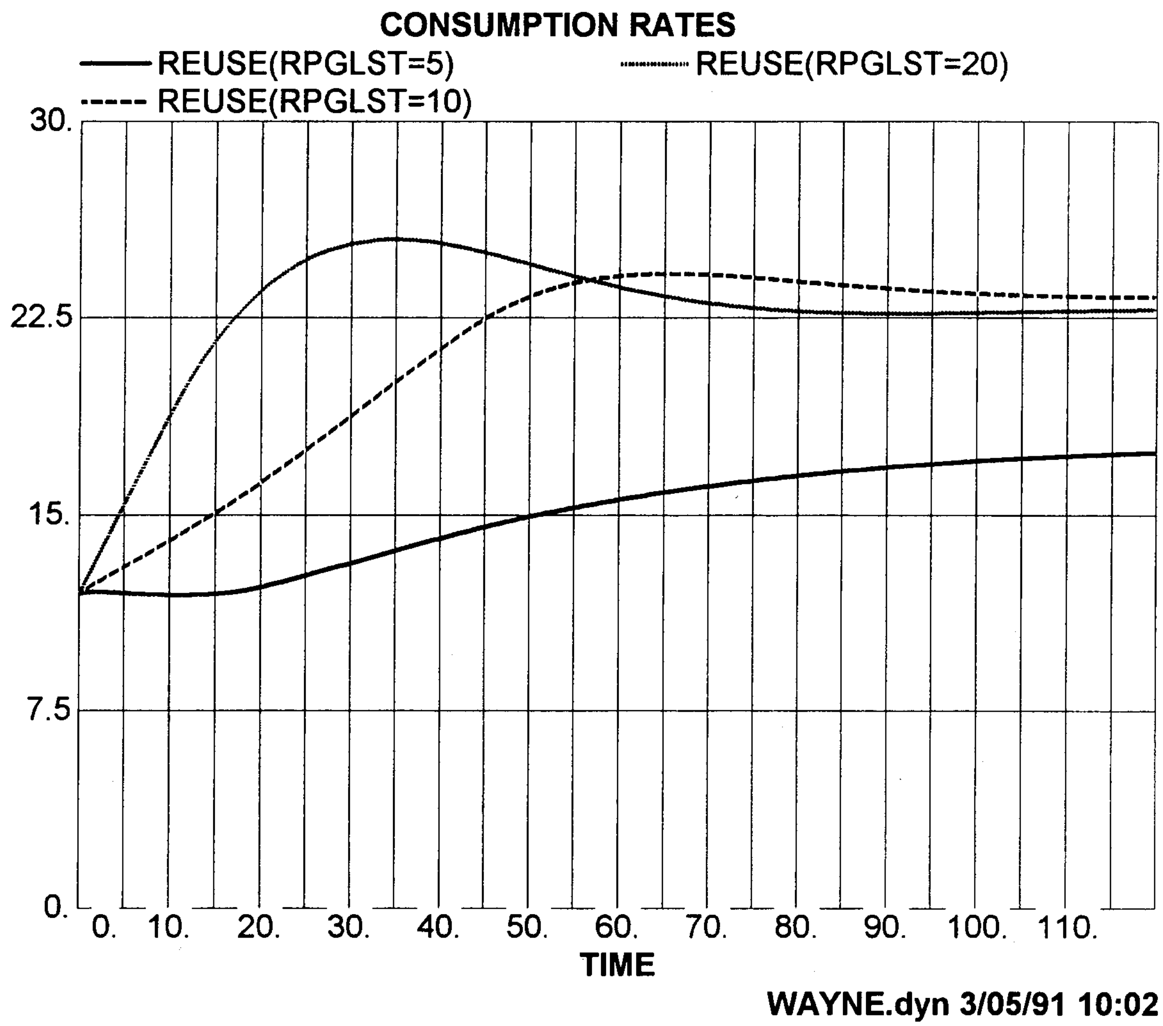


**Figure 4: Impact of Production Goal on *Reuse Rate* (*Production Goal* = 5, 10, 20 STPRGL = 0)**

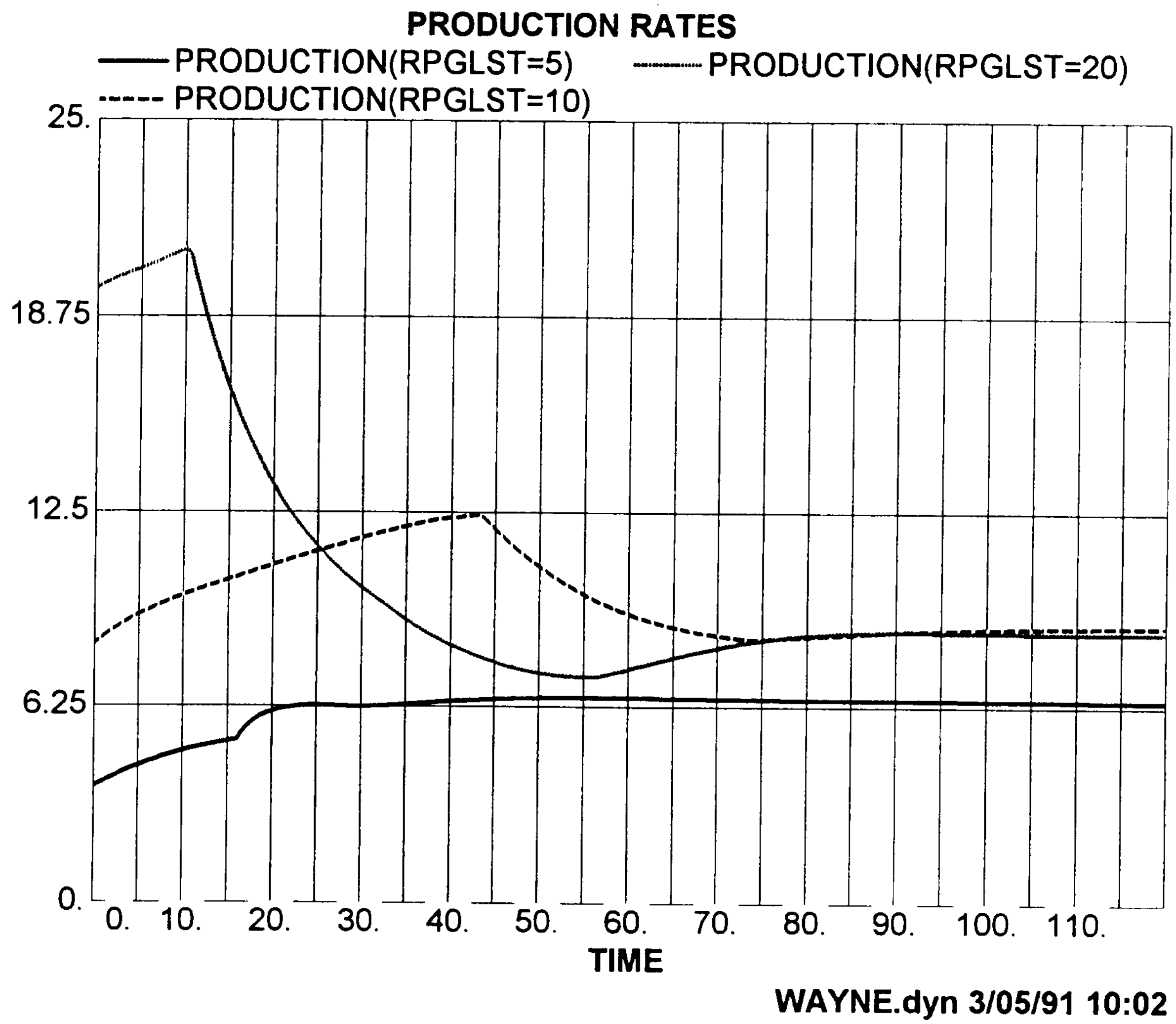


**Figure 5: Impact of Production Goal on *Production Rate* (*Production Goal* = 5, 10, 20 STPRGL = 0)**

*Production Cost* captures the relative cost of producing a reusable component. With a value of 2, this means that a reusable component takes twice as much development effort to produce as one that is not reusable.

A series of six ten-year simulations was conducted . In the first series, *Production Cost* was fixed at the value of 2, but *Consumption Cost* was varied from .5, to .25, and to .1. For the next series, *Production Cost* was changed to 4 and *Consumption Cost* was again varied again from .5, to .25, and to .1.

Results from the six runs are summarized in Figure 6. On the x-axis is a measure of relative productivity between consumption and production and is calculated as *Production Cost* (NMEXTR)/*Consumption Cost* (NMFRRU). On the y-axis is the stable *Reuse Rate* achieved at the end of the ten-year simulation. The three points at the top portion of the figure represent the first series of runs and the three points at the bottom of the figure represent the second series of runs. Long-term *Reuse Rate* does not go down as *Consumption Cost* is decreased. *Reuse Rate* only decreases when *Production Cost* is doubled. Based on these results, *Consumption Cost* does not appear to affect long-term *Reuse Rate* appreciably while *Production Cost* does have a detectable effect.

To verify this conclusion, *Reuse Rate* and *Repository Size* variables were plotted at the different *Production Cost* and *Consumption Cost* values shown in Figures 7 and 8. *Reuse Rate* and *Repository Size* does indeed decrease as *Production Cost* increases. On the other hand, the change in *Repository Size* is

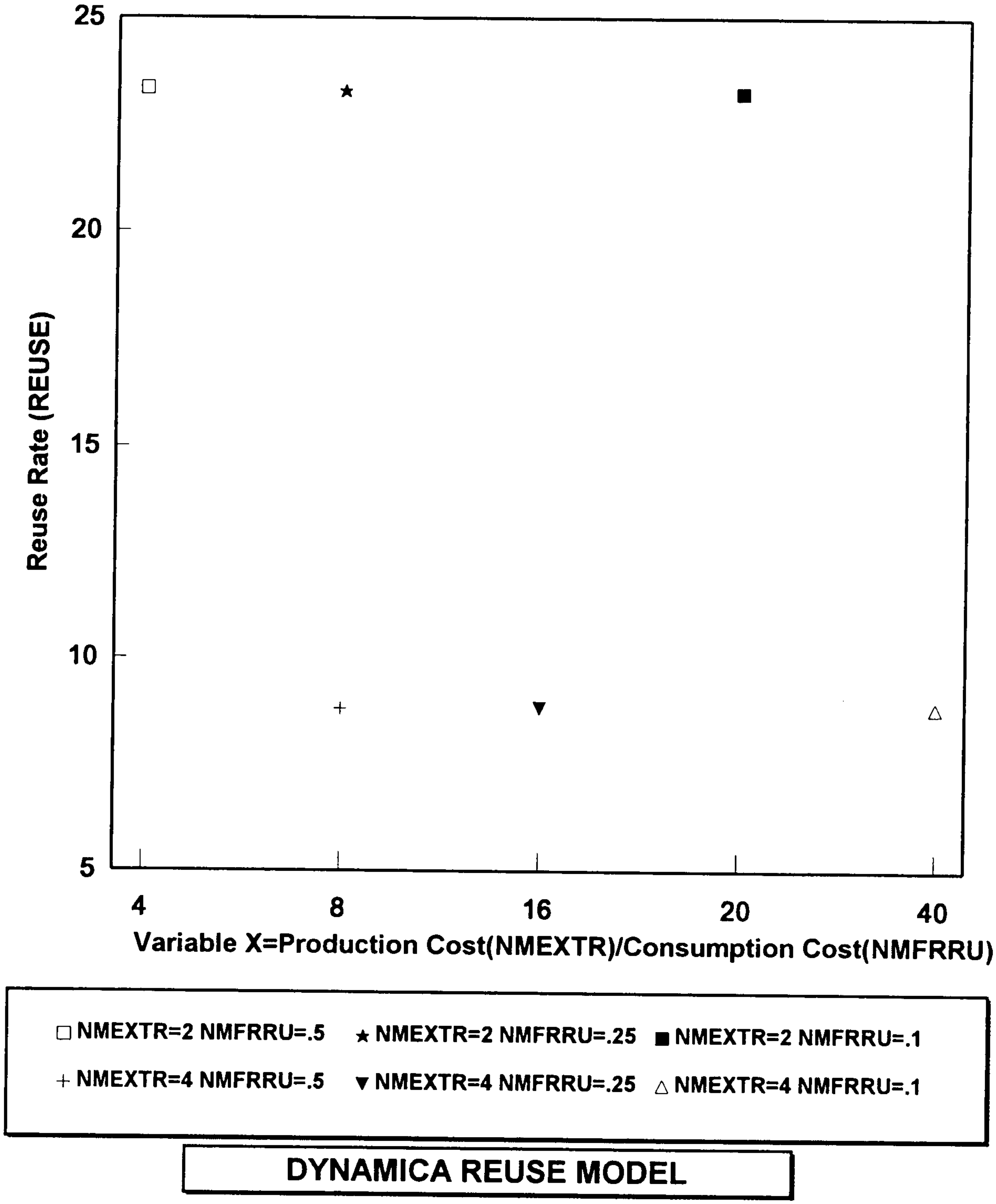


**Figure 6:** ***Reuse Rate*** **versus Variable X**

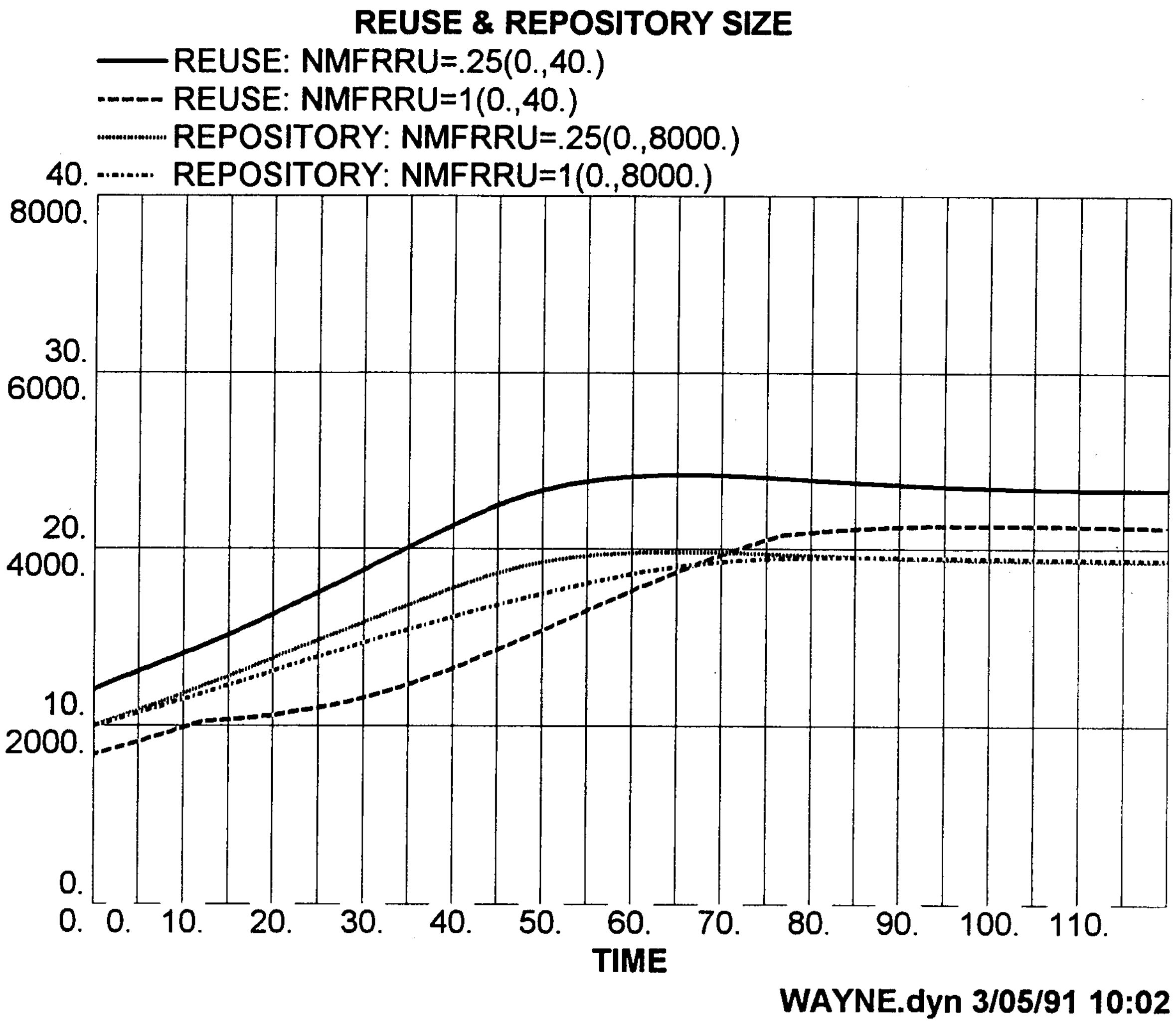


**Figure 7: Impact of Increasing Consumption Cost on *Reuse Rate* and *Repository Size* (*Consumption Cost* = .25 and 1)**

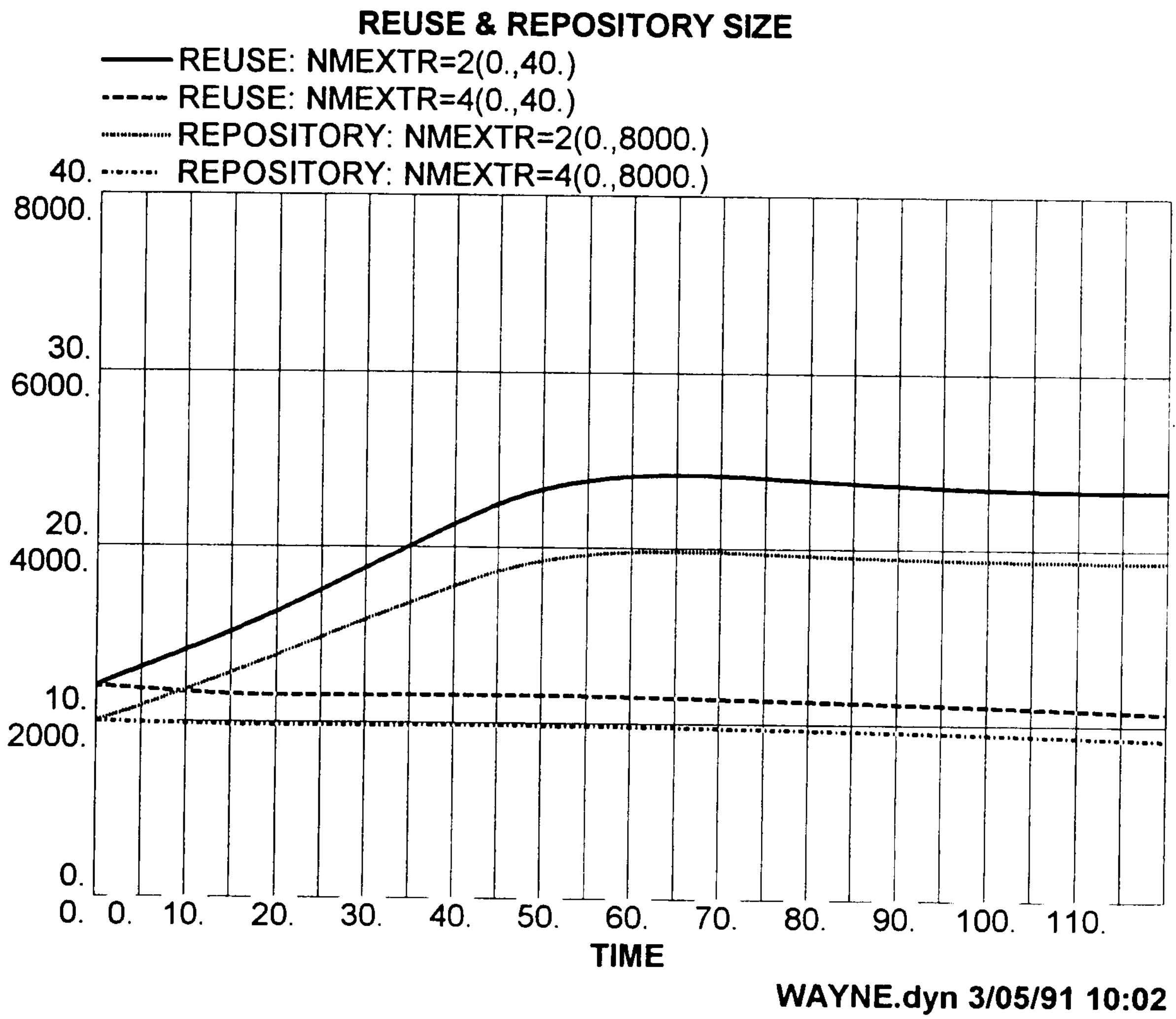


**Figure 8: Impact of Increasing Production Cost on *Reuse Rate* and *Repository Size* (*Production Cost* = 2 and 4)**

insignificant and the decrease in *Reuse Rate* is much less when *Consumption Cost* is increased.

**D. EMPLOYEE TURNOVER**

The Dynamica Reuse Model was used to determine the impact on *Reuse Rate* of various human resource management variables. The first series concerned changing the turnover rate from a relatively stable environment to one of high turnover, i.e., short employment duration. *Average Employment* was decreased from 42 to 21 months to reflect increasing turnover. Figure 9 represents a comparison of the *Fraction of Experienced Personnel* and *Reuse Rate* at the different employment times of 21 and 42 months. As expected with shorter employment time (i.e., higher turnover), the fraction decreases. With a higher turnover and lower level of experienced personnel, *Reuse Rate* would be expected to decrease and Figure 9 confirms this. Figure 10 shows *Fraction on Experienced Personnel* and *Adjusted Production Rate* for the scenario just described. Conversely, *Adjusted Production Rate* does not vary significantly with a higher turnover rate.

The next series of simulation runs were made to determine the impact of an abrupt loss of workforce. The variable PHGHWF was used to cause an abrupt drop in workforce level. Figures 11 and 12 show the impact on *Total Workforce* and *Reuse Rate* as PHGHWF is changed from 0 (the nominal value) to .25.

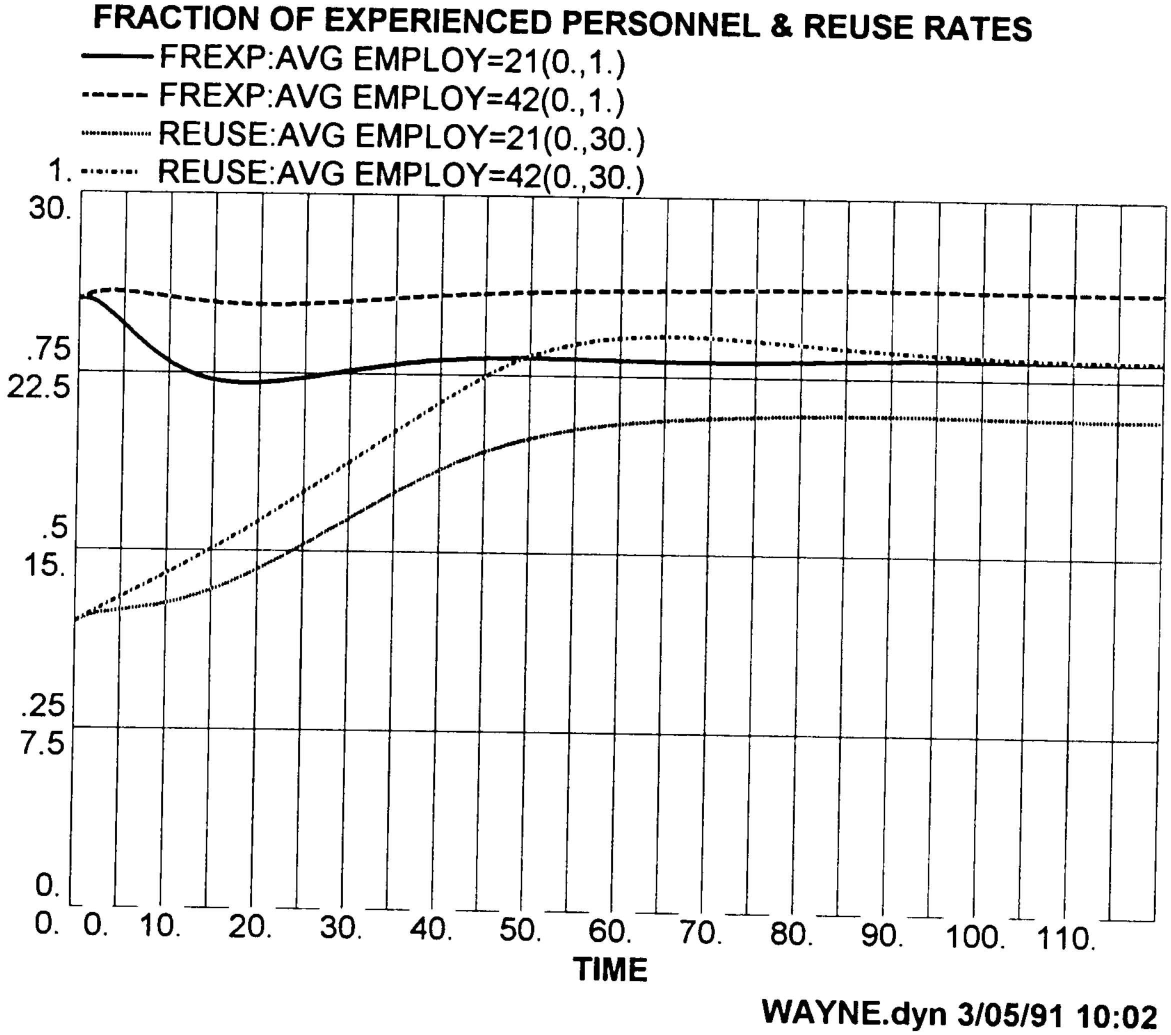


**Figure 9: Impact of Decreasing Employment Time on *Fraction of Experienced Personnel & Reuse Rate* (*Average Employment*= 21 and 42 months)**

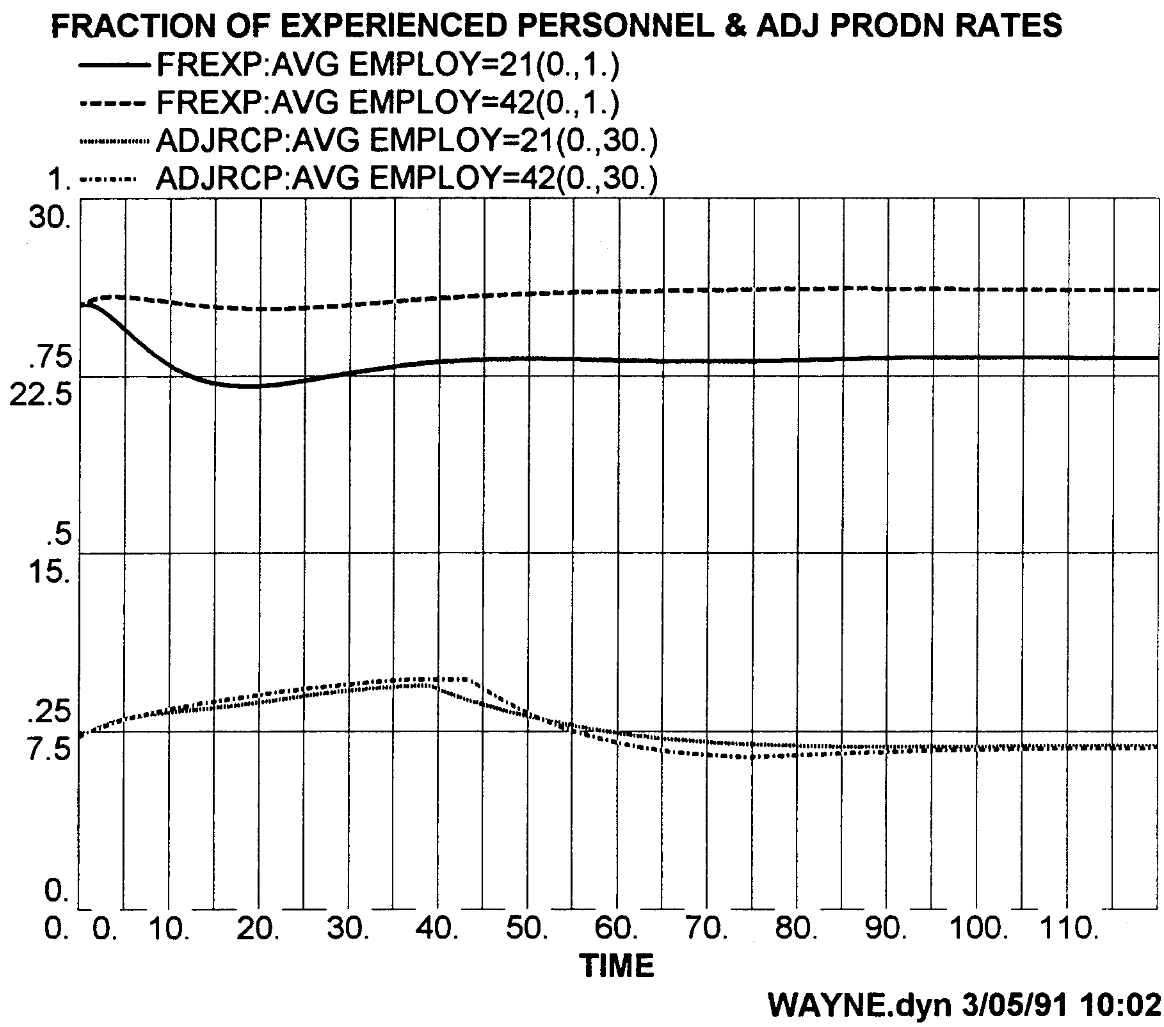


**Figure 10: Impact of Decreasing Employment Time on *Fraction of Experienced Personnel & Adjusted Production Rate* (*Average Employment*= 21 & 42 months)**

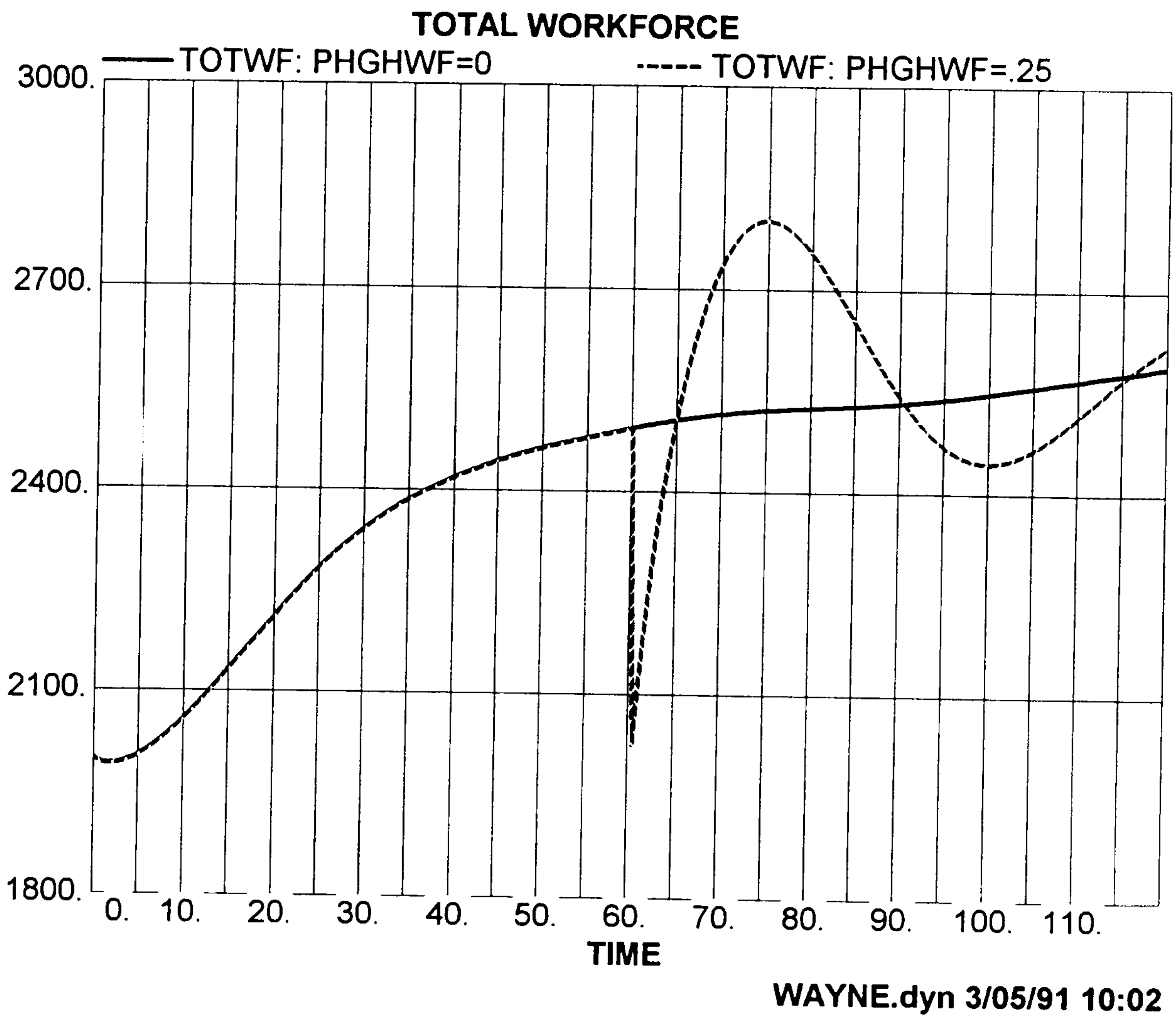


**Figure 11: Impact of 25% Reduction in Workforce on *Total Workforce* (PHGHWF = 0 and .25)**

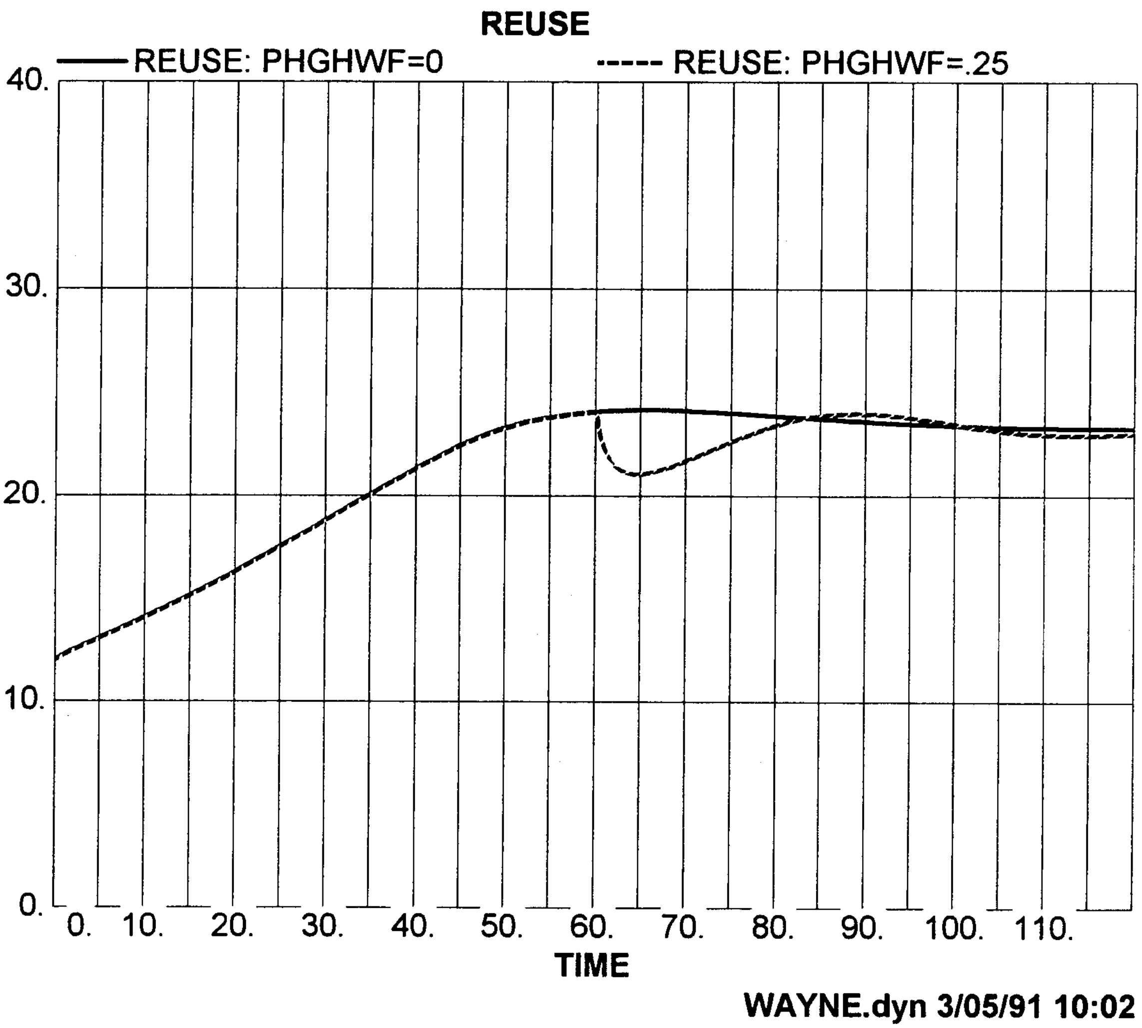


**Figure 12: Impact of 25% Reduction in Workforce on *Reuse Rate* (PHGHWF = 0 and .25)**

This established a one-time sudden 25% drop of the workforce. *Reuse Rate* initially goes down but over the long-term it returns to its nominal stable level.

## E. REPOSITORY SIZE

The Dynamica Reuse Model was used to determine the effect of *Repository Size* on *Reuse Rate*. Simulations were conducted varying the size of the repository with a single pulse. The variable PHGHRP was set at a series of different values, ± .25, ±.50, and ±.75, to represent varying degrees of externally imposed increases and decreases of *Repository Size.*

Figure 13 represents the nominal case of no perturbation in *Repository Size.* As indicated, *Reuse Rate* and *Adjusted Production Rate* stabilize at sixty months. Because of this, the pulse in *Repository Size* was activated at this point in time for all simulations.

Figures 14 and 15 represent pulses of ± 25%, i.e., increase/decrease in repository size by 25%. *Reuse Rates, Adjusted Production Rates and Repository Size* were instantaneously affected but over time stabilize to their nominal long-term levels indicated in Figure 13. The time to stabilize for the increase in *Repository Size* is much longer.

In Figures 16 and 17, pulses of ± 50% were used. The same pattern of short-term effect and long-term trend to stabilize is observed. In Figures 18 and 19, pulses of ± 75% were introduced and similar results were also demonstrated.

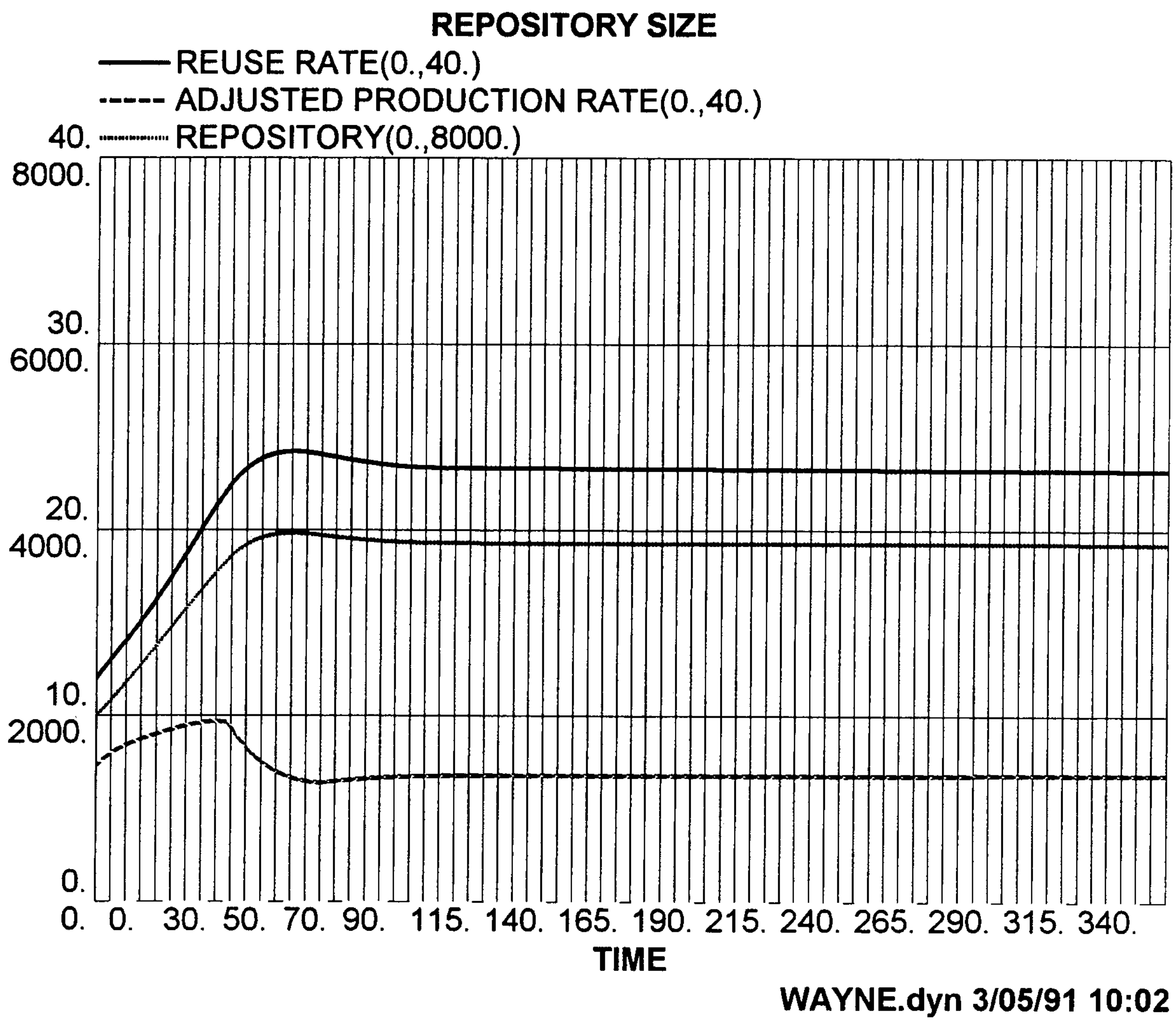


**Figure 13: Nominal Case of *Reuse Rate, Adjusted Production Rate* and *Repository Size***

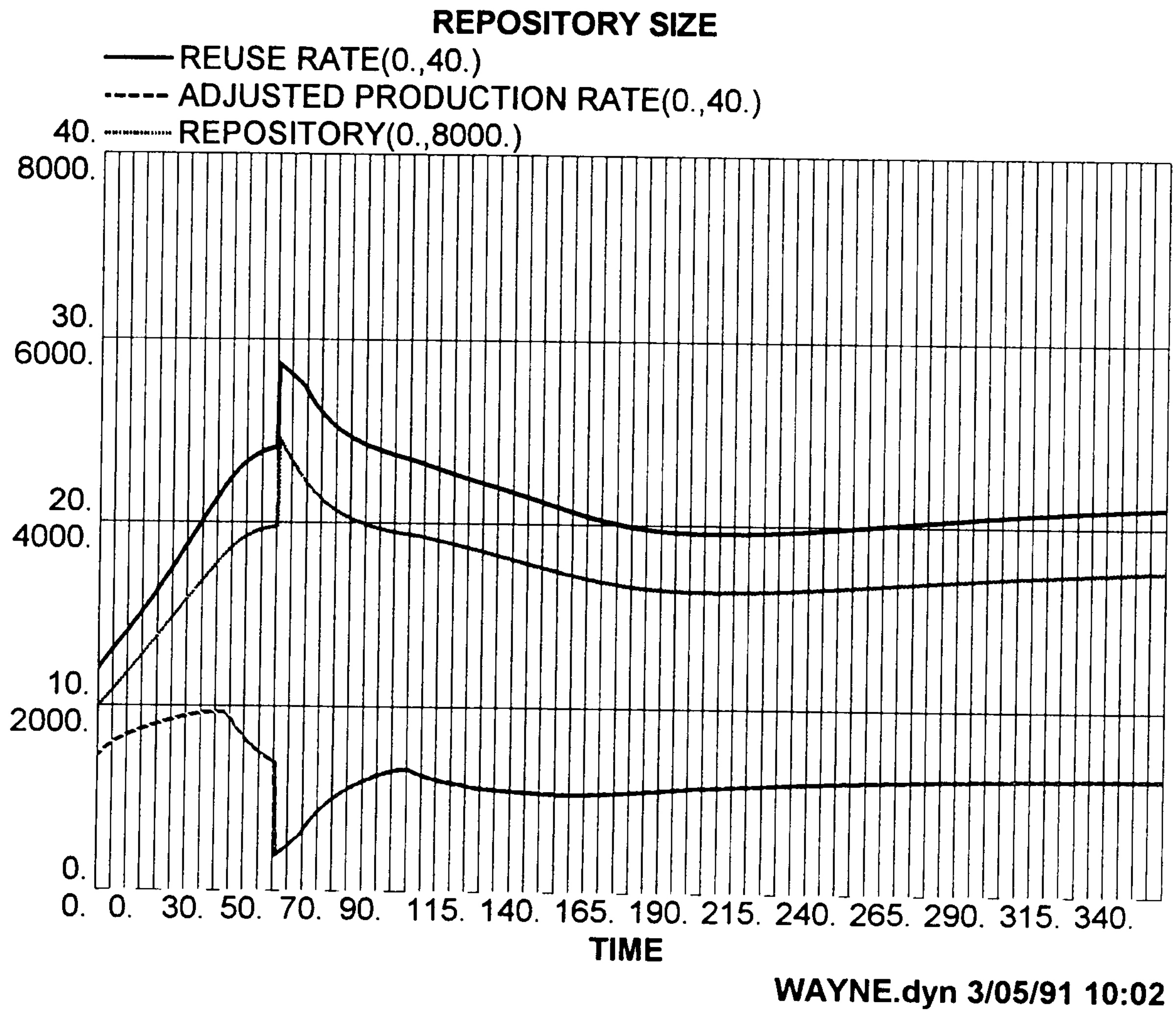


**Figure 14: Impact of +25% Pulse to the Repository Size on *Reuse Rate, Adjusted Production Rate* and *Repository Size* (PHGHRP = +.25)**

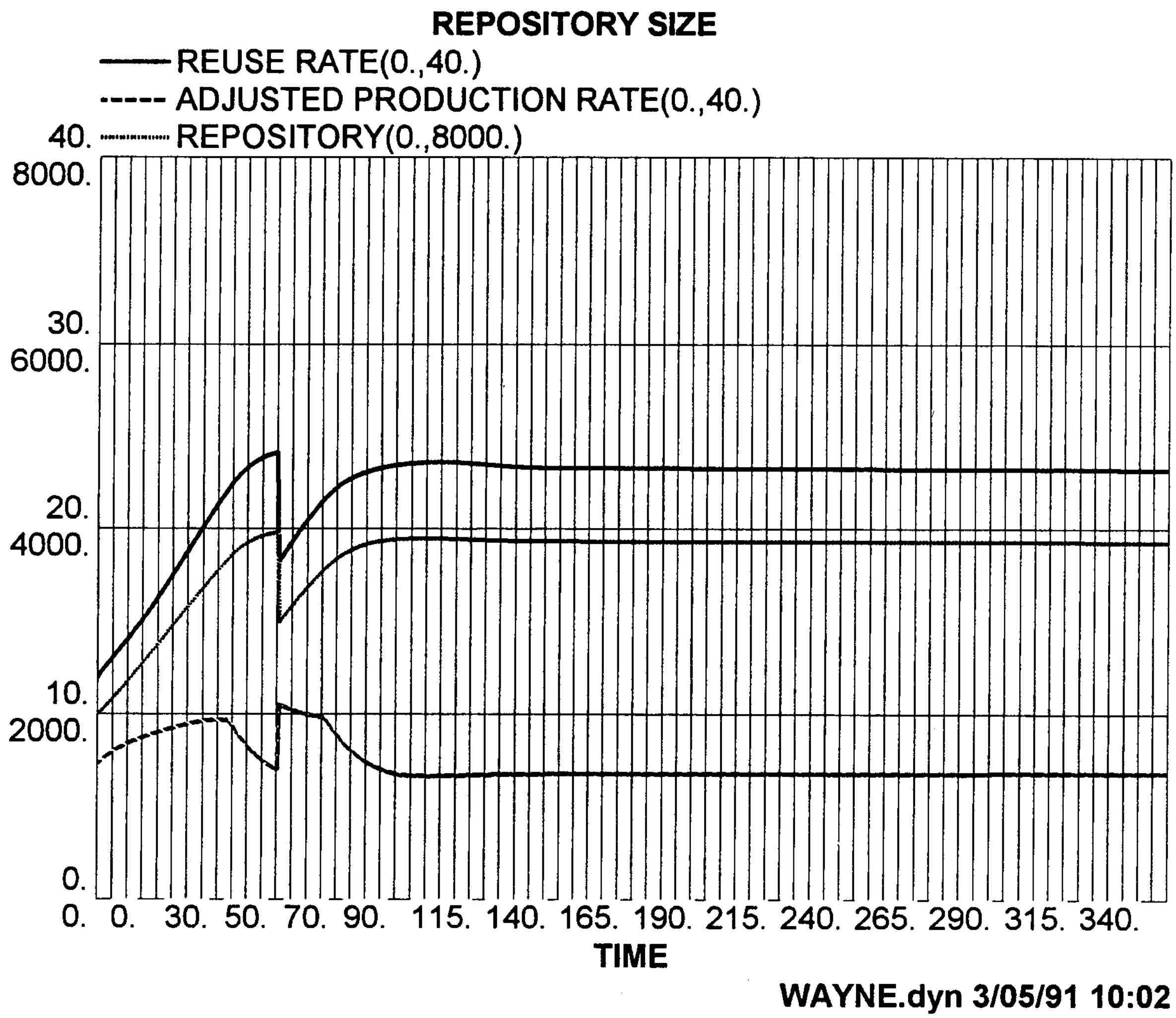


**Figure 15: Impact of -25% Pulse to the Repository Size on *Reuse Rate, Adjusted Production Rate* and *Repository Size* (PHGHRP = -.25)**

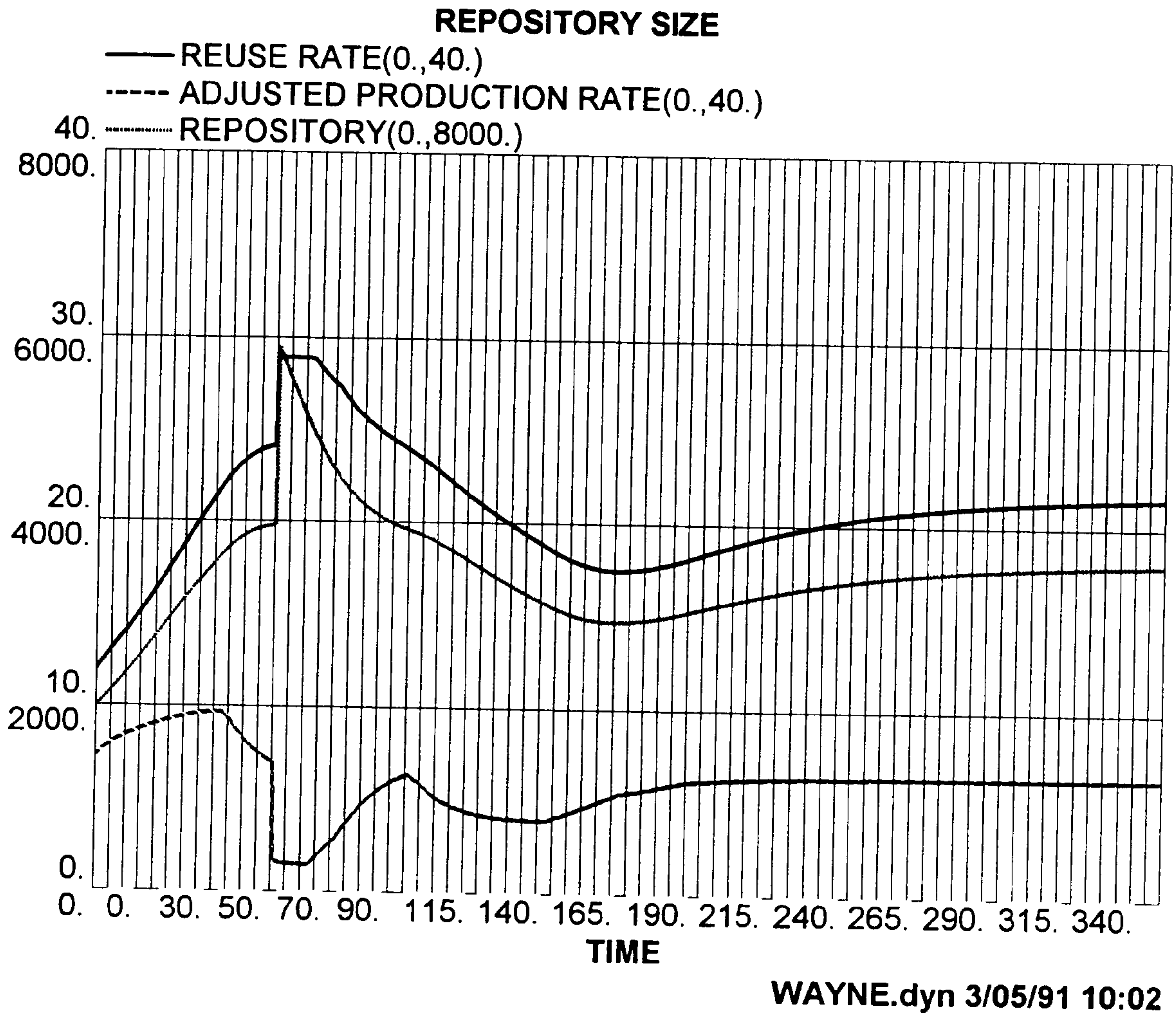


**Figure 16: Impact of +50% Pulse to the Repository Size on *Reuse Rate, Adjusted Production Rate* and *Repository Size* (PHGHRP = +.50)**

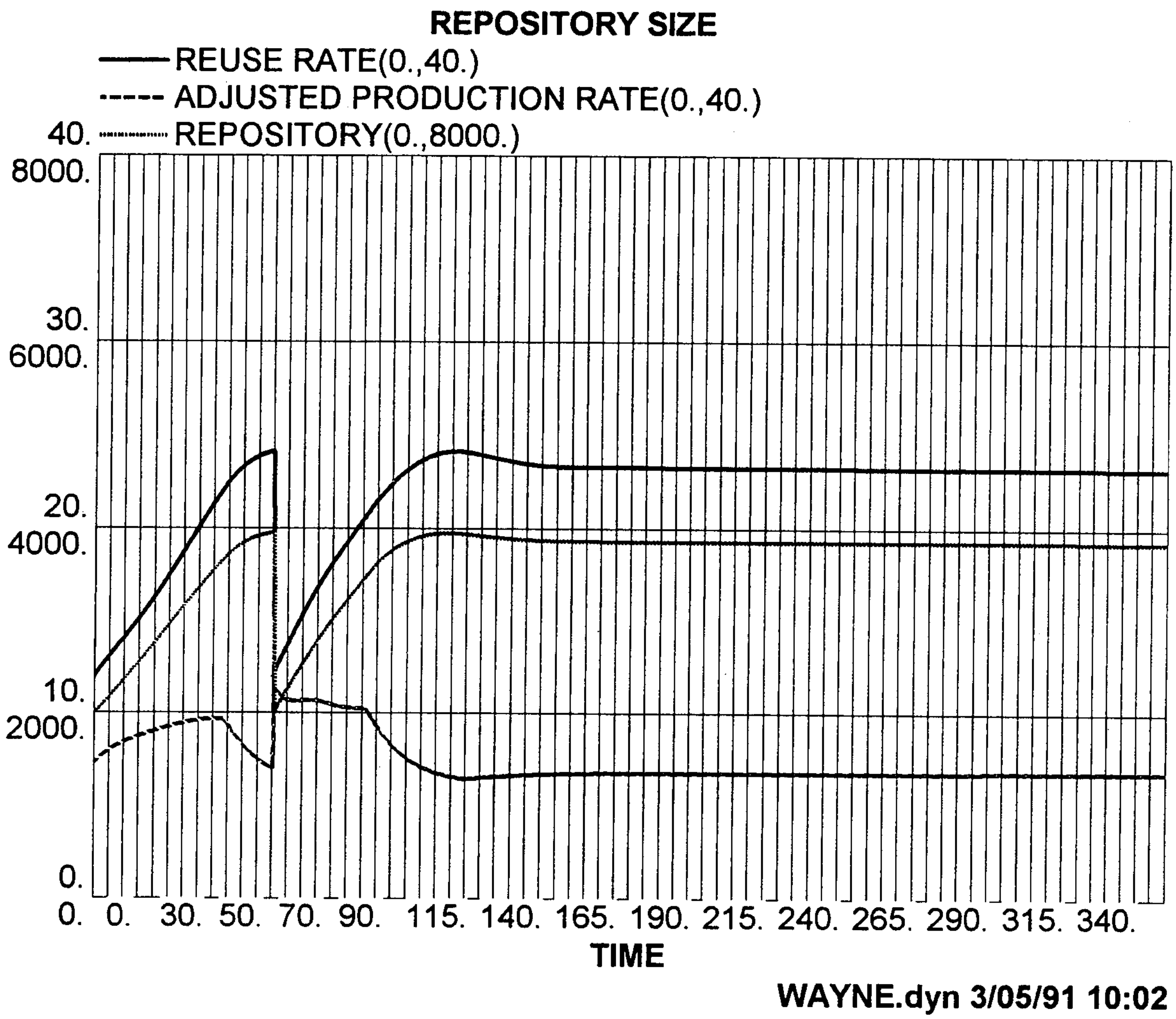


**Figure 17: Impact of -50% Pulse to the Repository Size on *Reuse Rate, Adjusted Production Rate* and *Repository Size* (PHGHRP = -.50)**

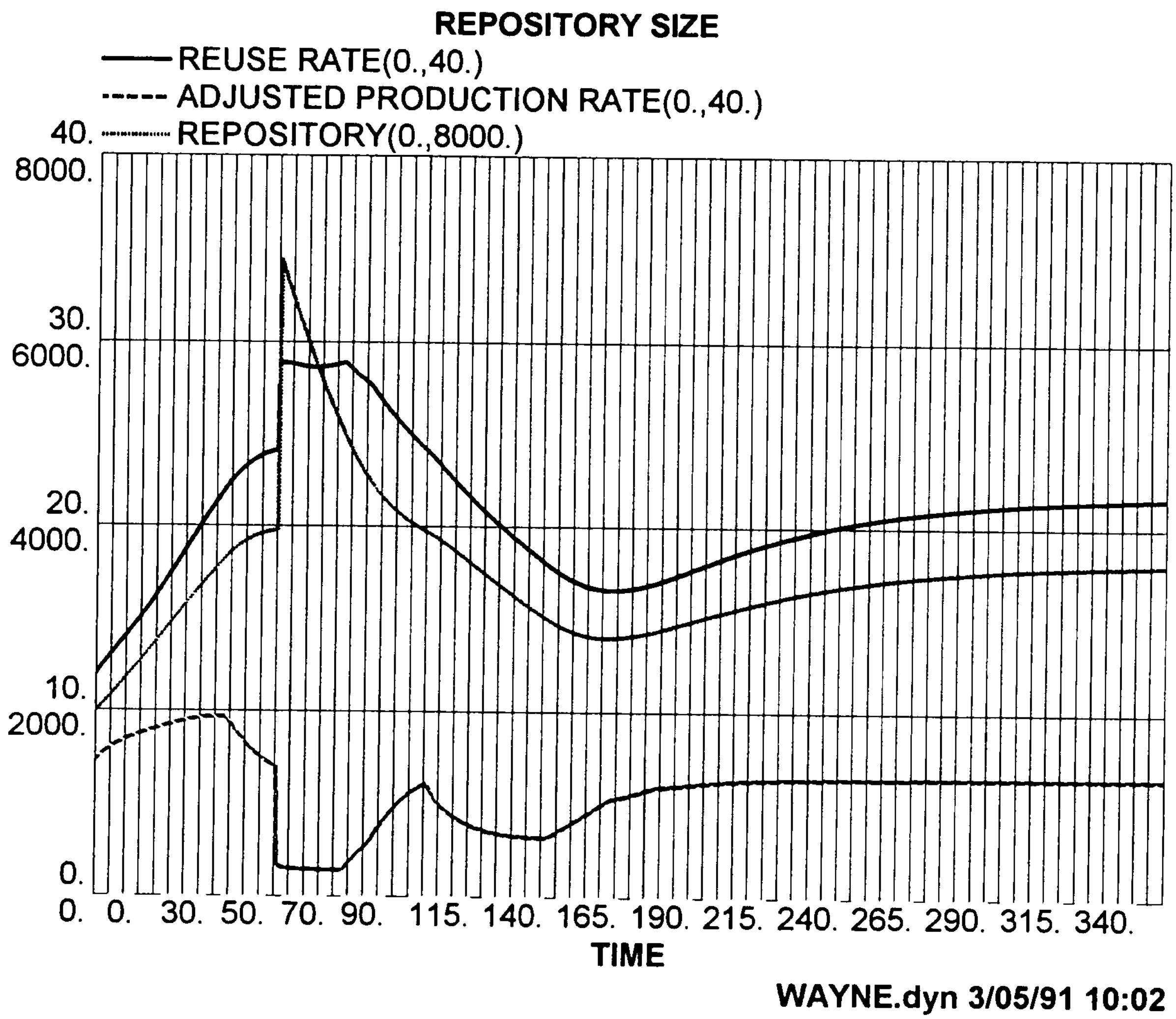


**Figure 18: Impact of +75% Pulse to the Repository Size on *Reuse Rate, Adjusted Production Rate* and *Repository Size* (PHGHRP = +.75)**

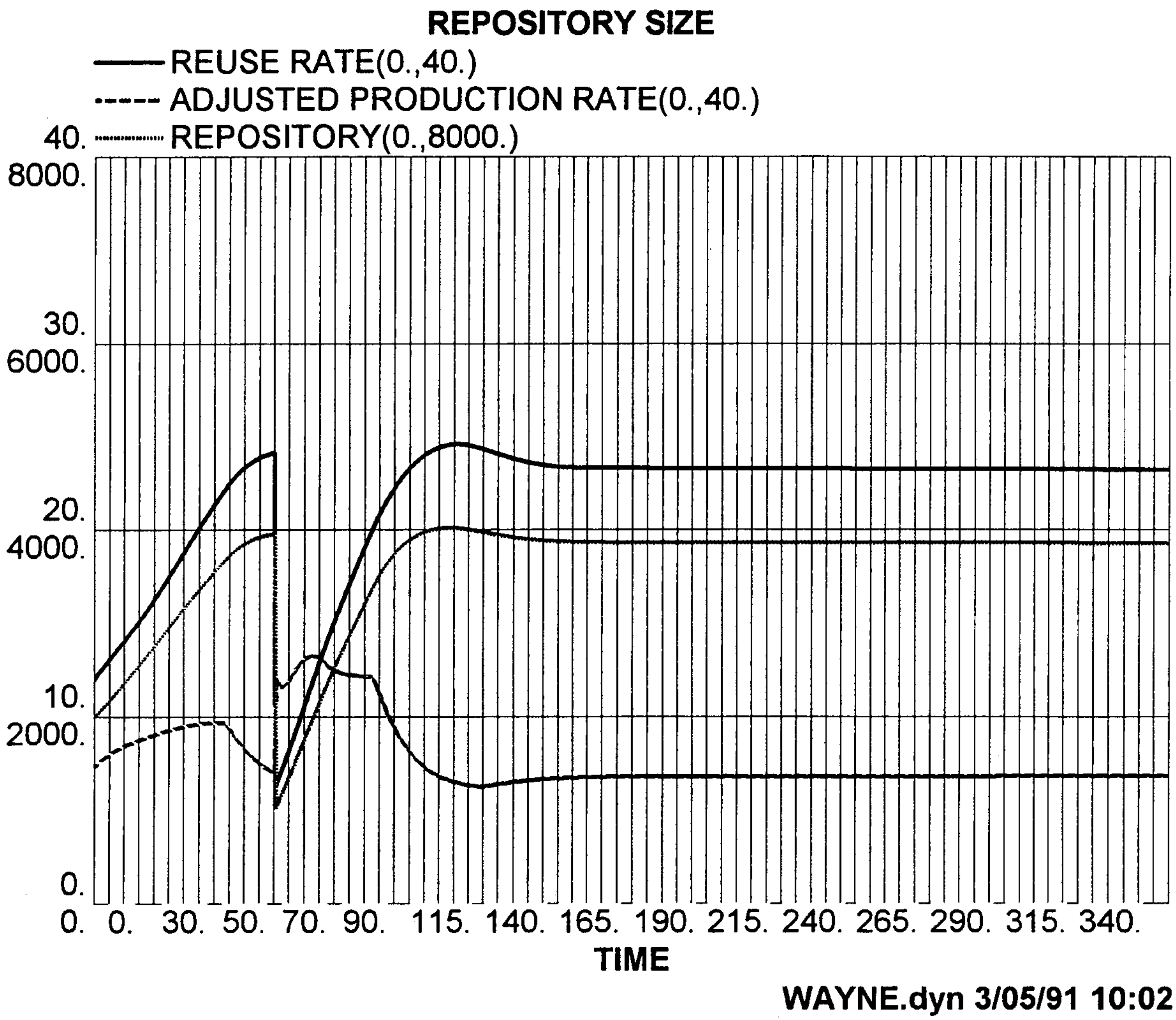


**Figure 19: Impact of -75% Pulse to the Repository Size on *Reuse Rate, Adjusted Production Rate* and *Repository Size* (PHGHRP = -.75)**

## F. SOFTWARE DEVELOPMENT RATE

The Dynamica Reuse Model was run for a series of simulations to determine the effect on *Reuse Rate* of the software development rate. *Software Development Rate* is the number of software components developed per month. Three software development scenarios were studied: (1) a stable rate, (2) a rising rate, and (3) a cyclic rate. The rate was changed by use of switches NMGRW1, and NMGRW4.

Figure 20 represents the first software development scenario. Figure 21 represents the second scenario. Figure 22 represents the third scenario. Figure 23 shows the three *Reuse Rates* together and Figure 24 shows the three *Software Development Rates* together. The results indicate reuse is directly affected by software development. A constant increase in software development causes a constant increase in reuse before stability is achieved at higher-than-nominal level. Similarly, a cyclic pattern of software development causes a cyclic pattern of reuse with *Reuse Rate* trailing the upward and downward trend of *Software Development Rate.*

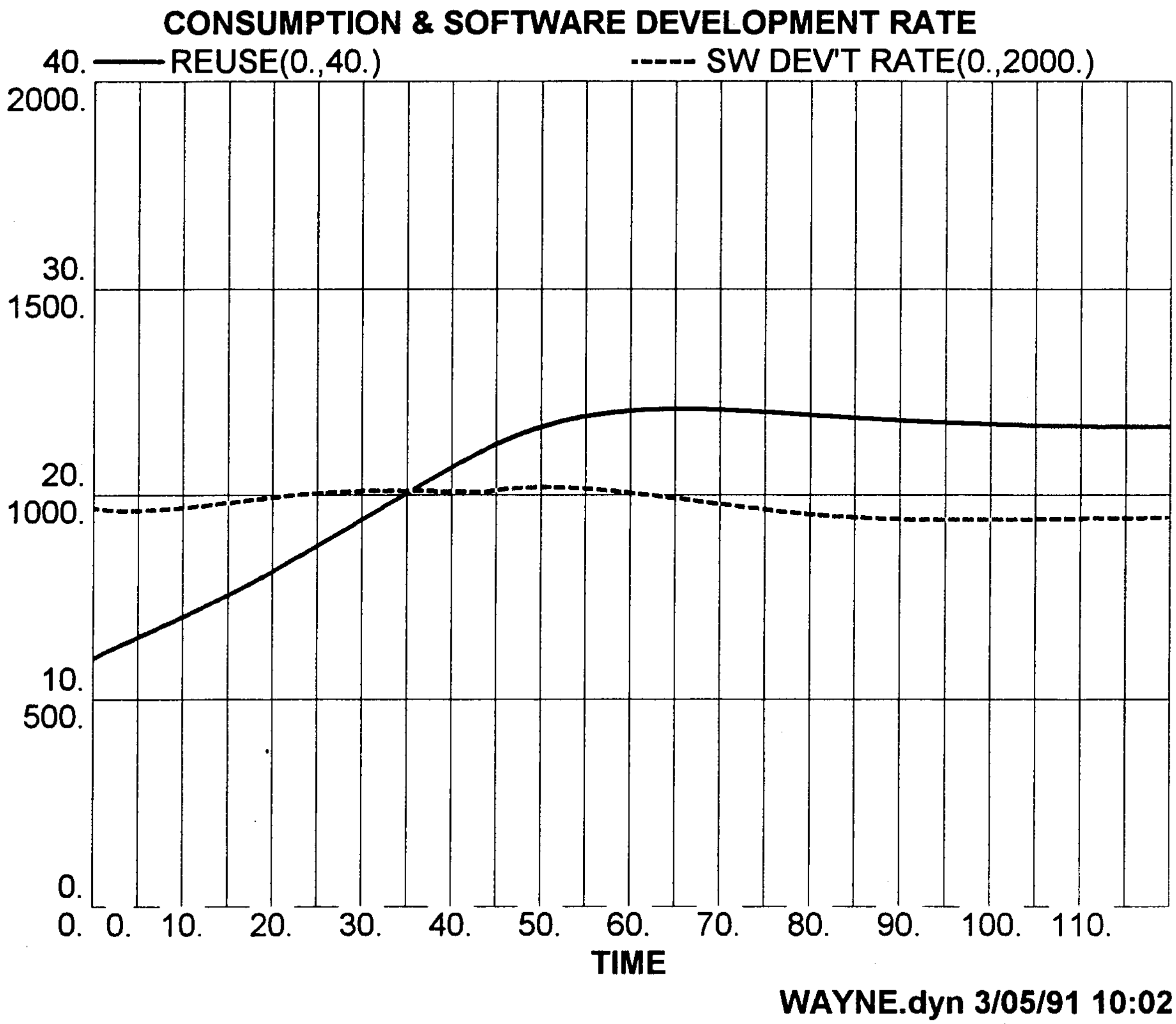


**Figure 20: Impact of Stable *Software Development Rate* on *Reuse Rate* (NMGRW1 =0, NMGRW4 =0)**

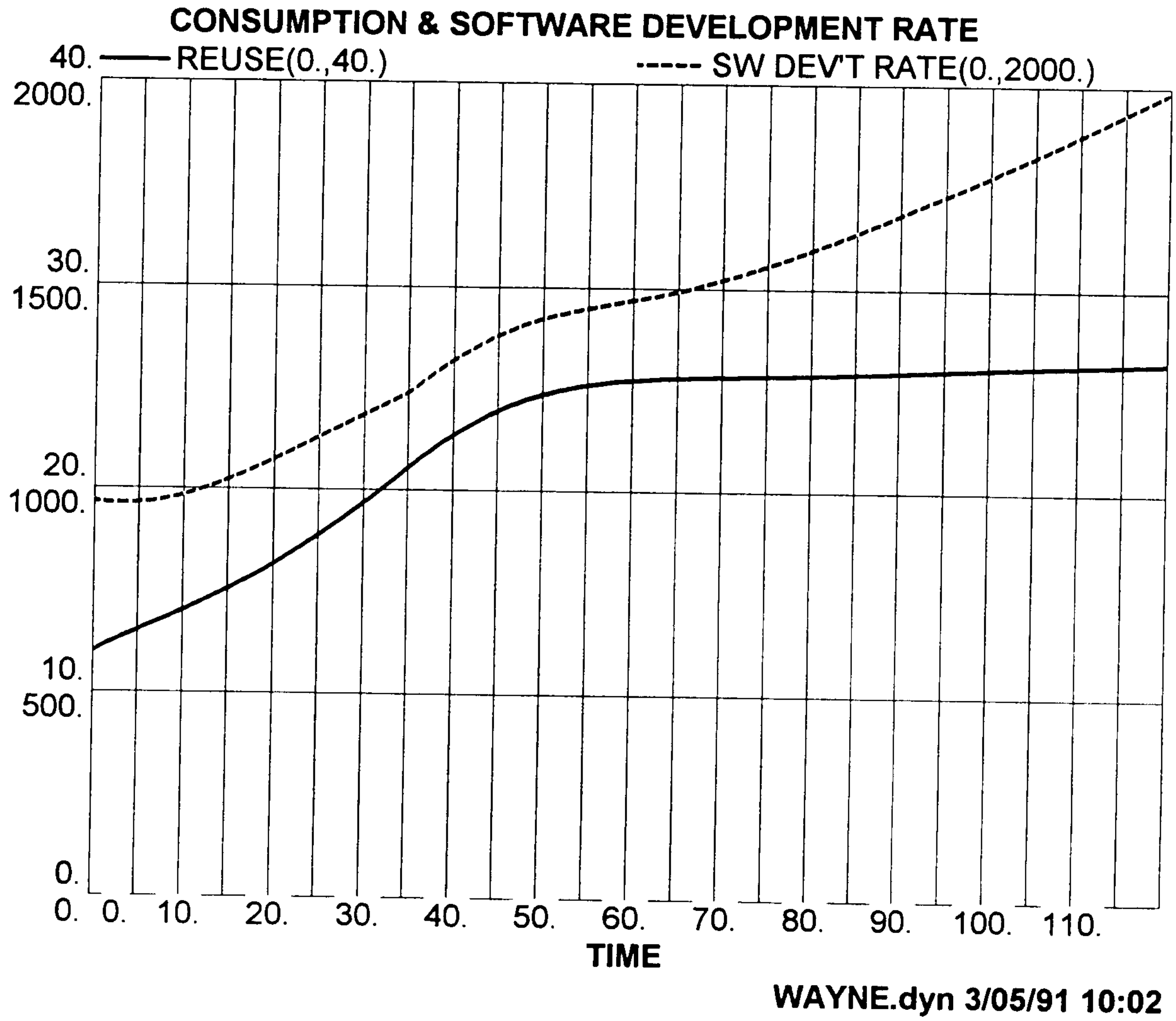


**Figure 21: Impact of Rising *Software Development Rate* on *Reuse Rate* (NMGRW1 =1, NMGRW4 =0)**

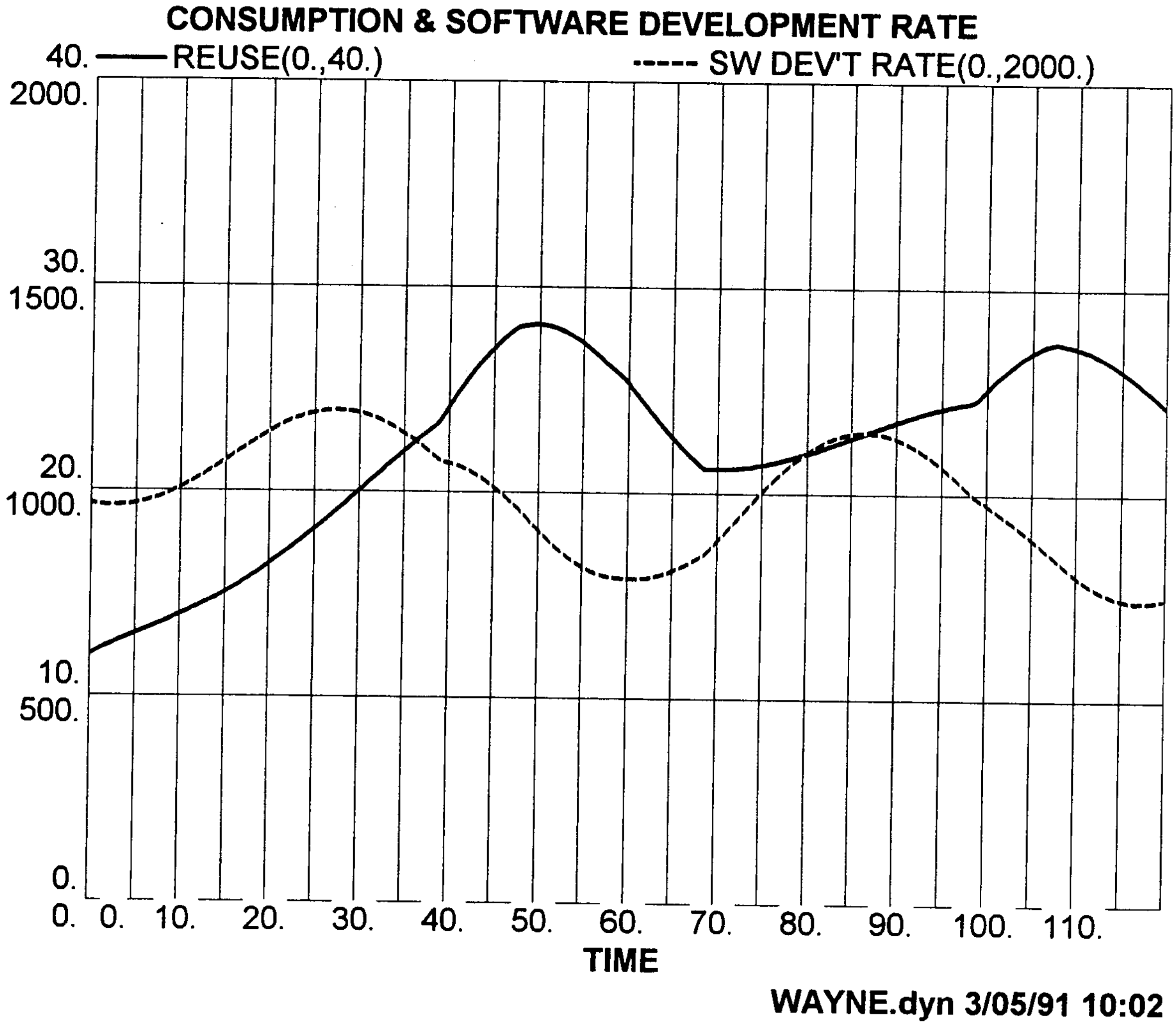


**Figure 22: Impact of Cyclic *Software Development Rate* on *Reuse Rate* (NMGRW1 =0, NMGRW4 =1)**

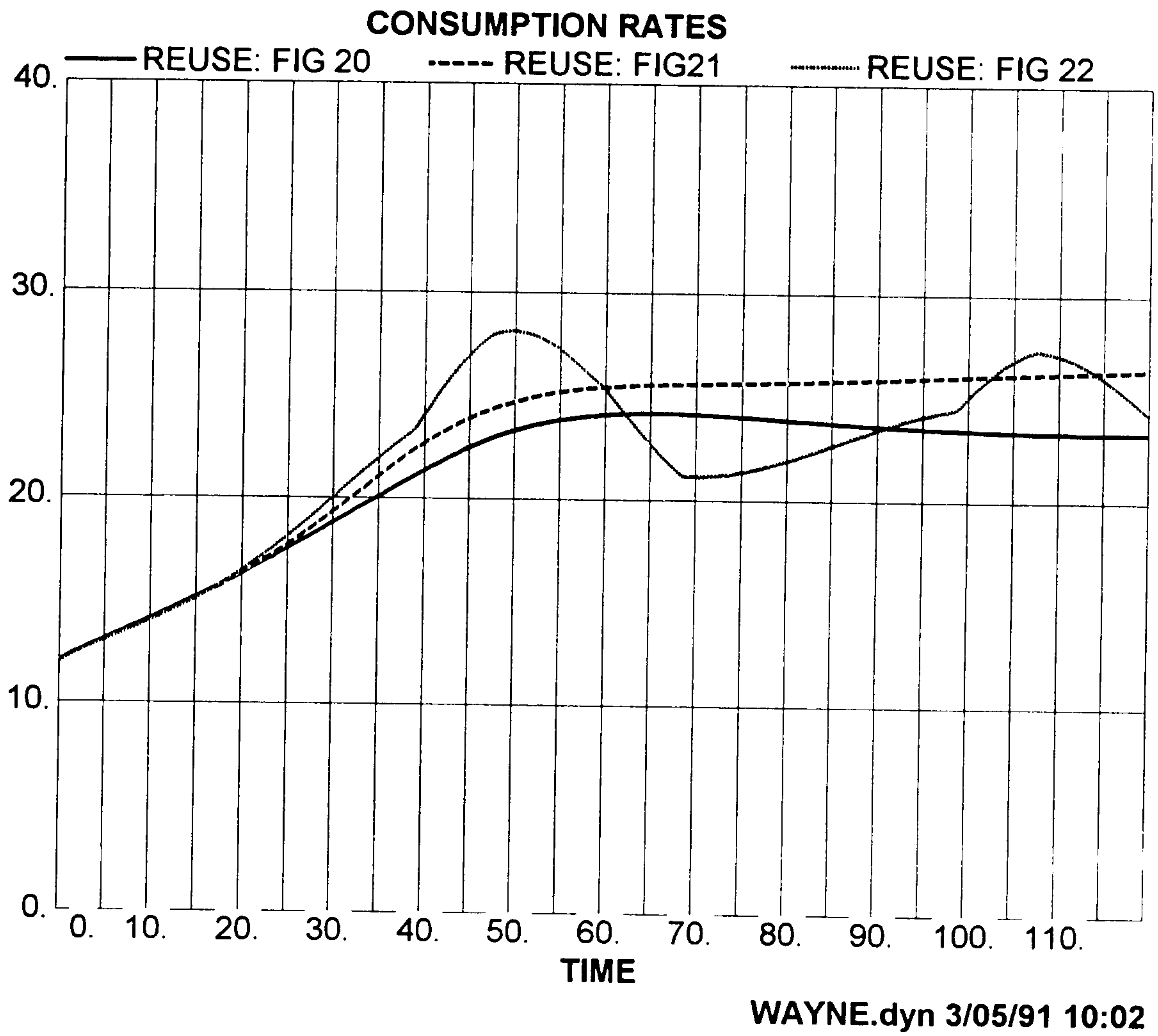


**Figure 23: Comparison of Varying *Software Development Rate* on *Reuse Rate* (NMGRW1 = 0,1,0 and NMGRW4 = 0,0,1)**

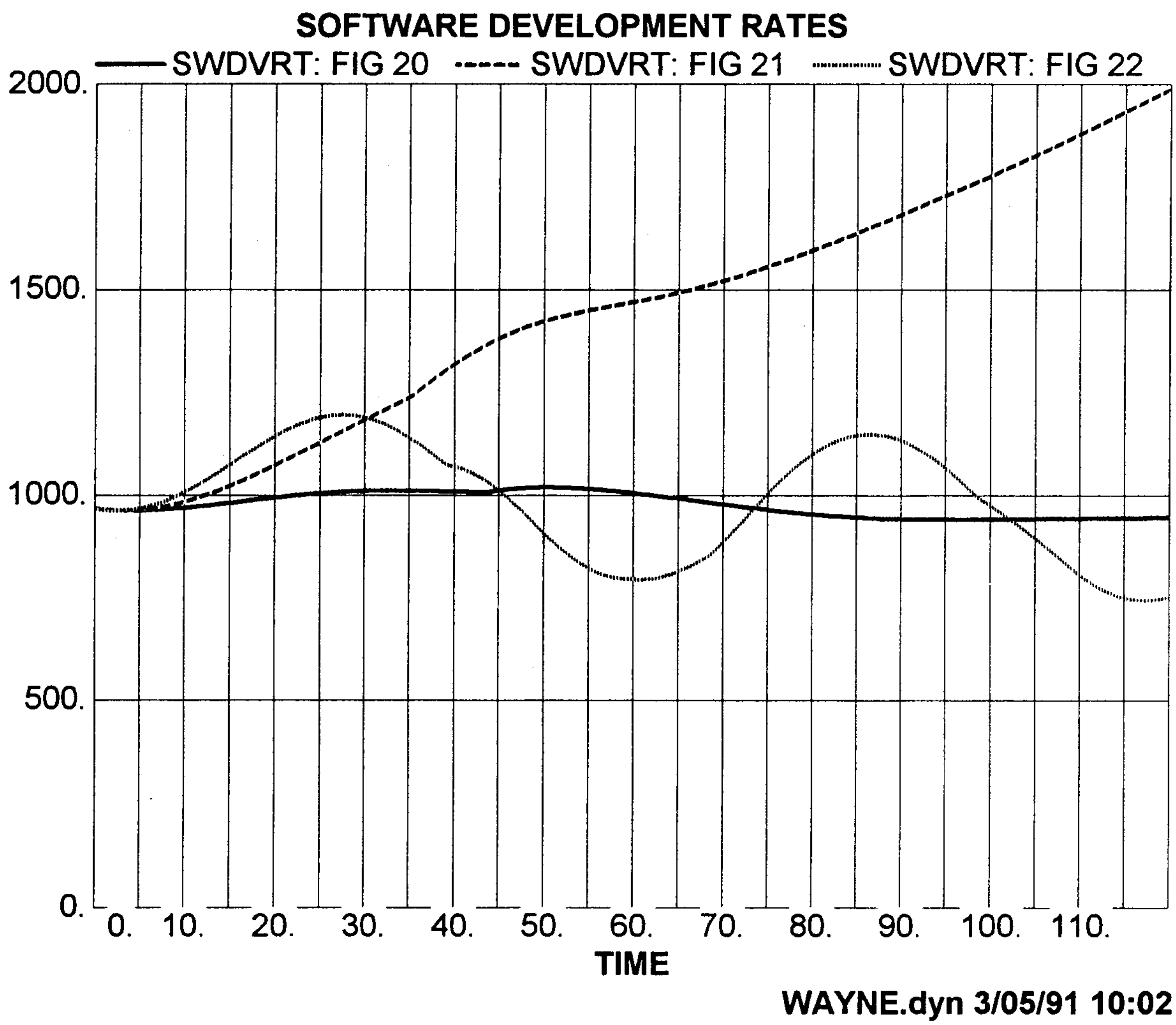


**Figure 24: Comparison of Varying *Software Development Rate* (NMGRW1 = 0,1,0 and NMGRW4 = 0,0,1)**

# V. CONCLUSIONS

## A. RESULTS

The Dynamica Reuse Model simulation results suggest several managerial actions that can be accomplished to ensure successful reuse. Because the model was able to enhance our understanding of the reuse process, managers can now plan a course of action without having to undertake costly, time-consuming experiments or trial runs of management actions.

In the area of consumption and production goals, managers need to realize that setting goals too low will lead to decreased reuse rates. A strategy of increasing the goals when it becomes clear that the goals are too low can now be employed. However, managers should not make the mistake of setting goals too high because reuse does not increase constantly but instead reaches a maximum value. Management issues dealing with controlling the cost of consumption and production can now be addressed with the knowledge that managing the production costs are more critical.

One of an organization's best asset is experienced employees. Reuse is enhanced by a low rate of turnover of personnel. Management should take actions to minimize staff turnover by providing incentives for their employees to stay such as providing competitive salaries.

One of the major undertakings in introducing a software reuse program is the establishment of a repository of reusable components. With the knowledge that there is a structurally stable repository size for any organization, managers can develop more rational plans for the needed resource levels to support their organizational repository. This information will apply to DoD as software reuse is institutionalized and taxpayers' dollars are spent building large libraries of reusable components. Management should also take action to stabilize the software development rate to achieve a more consistent reuse rate.

## B. RECOMMENDATIONS FOR FOLLOW-ON STUDY

The Dynamic Reuse Model can be used to conduct follow-on studies in all facets of the software reuse environment. Because the model can be customized to an organization's individual specifications, studies can be conducted across the entire range of software developing organizations. The complete spectrum of managerial and technical issues of the software reuse process can be analyzed. One potential area of study is to extend the model to a multi-organization situation such as DoD, where reuse is practiced between organizations as well as within a particular organization.

# APPENDIX A: GLOSSARY

***Adjusted Production Rate;*** Dynamica Reuse Model variable: **ADJRCP**; The number of reusable components' production as a percentage of new component production.

***Average Employment;*** Dynamica Reuse Model variable: **AVEMPT**; The average employment time in months.

***Consumption Cost;*** Dynamica Reuse Model variable: **NMFRRU**; The nominal fraction of development effort to reuse a component. A value of one means it is the same relative cost to use a reusable component as the cost to use an all-new component. A value of less than one means it costs less to reuse a component in an application than to use an all-new component.

***Fraction of Experienced Personnel;*** Dynamica Reuse Model variable: **FREXP**; The number of total personnel who are experienced as a percentage of total personnel.

***Production Cost*****;** Dynamica Reuse Model variable: **NMEXTR**; The nominal fraction of cost to produce a reusable component. A value of two means the relative cost to produce a reusable component is twice as much as the cost to produce a non-reusable component.

***Production Goal***; Dynamica Reuse Model variable: **RPRDGL;** Production of components' goal throughout simulation run.

***Production Goal Initial***; Dynamica Reuse Model variable: **RPGLST;** Production of components' goal at start of simulation.

***Production Rate;*** Dynamica Reuse Model variable: **RCPRPR**; Number of production of reusable components as a percentage of total production.

***Repository Size;*** Dynamica Reuse Model variable: **RPSTRY**; Represents the number of reusable components in the organization's reusable component repository.

***Reuse Rate***; Dynamica Reuse Model variable: **REUSE**; The rate at which components are reused and is expressed as the number of reusable components used divided by the total number of components, i.e., both reusable and new.

***Reuse Goal Initial***; Dynamica Reuse Model variable: **RUGLST**; Goal for reuse rate at start of simulation run.

***Reuse Goal***; Dynamica Reuse Model variable: **RUGOAL**; Goal for reuse rate throughout simulation run.

***Software Development Rate*;** Dynamica Reuse Model variable: **SWDVRT**; The number of software components being developed per month. Rate includes all software developed by the organization, i.e., both new and reused.

***Total Workforce*;** Dynamica Reuse Model variable: **TOTWF**; The total number of personnel in the organization.

# APPENDIX B: CONSUMPTION AND PRODUCTION GOALS DOCUMENTATION

Model = REUSE6; Mgt Goals RUGLST=5 RPGLST=10 STRUGL=0

| Years | REUSE | RCPRPR | ADJRCP | RUGOAL | RPRDGL |
|---|---|---|---|---|---|
| 0 | 11.42 | 8.46 | 7.50 | 5.00 | 10.00 |
| 1 | 12.36 | 9.81 | 8.60 | 5.00 | 10.00 |
| 2 | 14.44 | 10.68 | 9.14 | 5.00 | 10.00 |
| 3 | 16.71 | 11.50 | 9.58 | 5.00 | 10.00 |
| 4 | 18.68 | 10.99 | 8.94 | 5.00 | 10.00 |
| 5 | 19.68 | 9.04 | 7.26 | 5.00 | 10.00 |
| 6 | 19.86 | 8.21 | 6.58 | 5.00 | 9.84 |
| 7 | 19.74 | 8.15 | 6.54 | 5.00 | 9.40 |
| 8 | 19.64 | 8.28 | 6.65 | 5.00 | 9.15 |
| 9 | 19.51 | 8.36 | 6.73 | 5.00 | 9.06 |
| 10 | 19.41 | 8.39 | 6.76 | 5.00 | 9.03 |

***Table B1: Dynamica Reuse Model Tabular Data for Figures 2 and 3***

Model = REUSE6; Mgt Goals RUGLST=15 RPGLST=10 STRUGL=0

| Years | REUSE | RCPRPR | ADJRCP | RUGOAL | RPRDGL |
|---|---|---|---|---|---|
| 0 | 11.98 | 8.28 | 7.29 | 15.00 | 10.00 |
| 1 | 14.46 | 10.02 | 8.57 | 15.00 | 9.99 |
| 2 | 17.24 | 11.14 | 9.22 | 15.00 | 9.99 |
| 3 | 20.31 | 12.11 | 9.65 | 15.00 | 9.99 |
| 4 | 23.01 | 11.22 | 8.64 | 15.00 | 9.99 |
| 5 | 24.09 | 9.26 | 7.03 | 15.00 | 9.99 |
| 6 | 24.12 | 8.50 | 6.45 | 15.00 | 9.73 |
| 7 | 23.79 | 8.60 | 6.56 | 15.00 | 9.28 |
| 8 | 23.51 | 8.75 | 6.69 | 15.00 | 9.08 |
| 9 | 23.36 | 8.82 | 6.76 | 15.00 | 9.02 |
| 10 | 23.31 | 8.85 | 6.79 | 15.00 | 9.01 |

***Table B2: Dynamica Reuse Model Tabular Data for Figures 2 and 3***

Model = REUSE6; Mgt Goals RUGLST=30 RPGLST=10 STRUGL=0

| Years | REUSE | RCPRPR | ADJRCP | RUGOAL | RPRDGL |
|---|---|---|---|---|---|
| 0 | 13.37 | 8.08 | 7.00 | 30.00 | 10.00 |
| 1 | 14.94 | 9.85 | 8.38 | 30.00 | 9.65 |
| 2 | 17.17 | 10.10 | 8.37 | 30.00 | 9.04 |
| 3 | 19.38 | 9.88 | 7.96 | 30.00 | 8.35 |
| 4 | 21.06 | 9.84 | 7.76 | 30.00 | 8.09 |
| 5 | 22.22 | 9.88 | 7.68 | 30.00 | 8.05 |
| 6 | 23.03 | 9.29 | 7.15 | 30.00 | 8.05 |
| 7 | 23.31 | 8.86 | 6.80 | 30.00 | 8.05 |
| 8 | 23.32 | 8.80 | 6.74 | 30.00 | 8.05 |
| 9 | 23.26 | 8.80 | 6.75 | 30.00 | 8.05 |
| 10 | 23.22 | 8.81 | 6.76 | 30.00 | 8.05 |

***Table B3: Dynamica Reuse Model Tabular Data for Figures 2 and 3***

Model = REUSE6; Mgt Goals RUGLST=15 RPGLST=5 STPRGL=0

| Years | REUSE | RCPRPR | ADJRCP | RUGOAL | RPRDGL |
|---|---|---|---|---|---|
| 0 | 11.98 | 3.71 | 3.27 | 15.00 | 5.00 |
| 1 | 11.93 | 4.96 | 4.37 | 15.99 | 5.00 |
| 2 | 12.58 | 6.26 | 5.47 | 16.32 | 5.00 |
| 3 | 13.73 | 6.34 | 5.47 | 17.15 | 5.00 |
| 4 | 14.79 | 6.52 | 5.55 | 18.25 | 5.00 |
| 5 | 15.60 | 6.53 | 5.51 | 19.44 | 5.00 |
| 6 | 16.20 | 6.50 | 5.44 | 20.55 | 5.00 |
| 7 | 16.65 | 6.47 | 5.40 | 21.49 | 5.00 |
| 8 | 16.99 | 6.47 | 5.37 | 22.27 | 5.00 |
| 9 | 17.23 | 6.45 | 5.34 | 22.91 | 5.00 |
| 10 | 17.39 | 6.43 | 5.31 | 23.35 | 5.00 |

***Table B4: Dynamica Reuse Model Tabular Data for Figures 4 and 5***

Model = REUSE6; Mgt Goals RUGLST=15 RPGLST=10 STPRGL=0

| Years | REUSE | RCPRPR | ADJRCP | RUGOAL | RPRDGL |
|---|---|---|---|---|---|
| 0 | 11.98 | 8.28 | 7.29 | 15.00 | 10.00 |
| 1 | 14.47 | 10.04 | 8.59 | 16.68 | 10.00 |
| 2 | 17.25 | 11.16 | 9.24 | 18.77 | 10.00 |
| 3 | 20.34 | 12.13 | 9.66 | 21.87 | 10.00 |
| 4 | 23.04 | 11.18 | 8.61 | 25.24 | 10.00 |
| 5 | 24.10 | 9.24 | 7.01 | 28.10 | 10.00 |
| 6 | 24.11 | 8.49 | 6.45 | 29.82 | 10.00 |
| 7 | 23.78 | 8.60 | 6.56 | 30.85 | 10.00 |
| 8 | 23.50 | 8.76 | 6.70 | 31.50 | 10.00 |
| 9 | 23.34 | 8.83 | 6.77 | 31.53 | 10.00 |
| 10 | 23.30 | 8.87 | 6.80 | 31.45 | 10.00 |

***Table B5: Dynamica Reuse Model Tabular Data for Figures 4 and 5***

Model = REUSE6; Mgt Goals RUGLST=15 RPGLST=20 STPRGL=0

| Years | REUSE | RCPRPR | ADJRCP | RUGOAL | RPRDGL |
|---|---|---|---|---|---|
| 0 | 11.98 | 19.66 | 17.31 | 15.00 | 20.00 |
| 1 | 20.11 | 19.03 | 15.21 | 18.36 | 20.00 |
| 2 | 24.54 | 11.73 | 8.85 | 24.30 | 20.00 |
| 3 | 25.49 | 8.88 | 6.61 | 28.78 | 20.00 |
| 4 | 24.73 | 7.46 | 5.61 | 30.97 | 20.00 |
| 5 | 23.67 | 7.47 | 5.70 | 31.87 | 20.00 |
| 6 | 22.99 | 8.27 | 6.37 | 31.96 | 20.00 |
| 7 | 22.71 | 8.65 | 6.69 | 31.67 | 20.00 |
| 8 | 22.68 | 8.68 | 6.71 | 31.34 | 20.00 |
| 9 | 22.76 | 8.66 | 6.69 | 31.09 | 20.00 |
| 10 | 22.81 | 8.64 | 6.67 | 30.93 | 20.00 |

***Table B6: Dynamica Reuse Model Tabular Data for Figures 4 and 5***

# APPENDIX C: RELATIVE PRODUCTIVITIES OF CONSUMPTION AND PRODUCTION DOCUMENTATION

| Years | REUSE |
|---|---|
| Model = REUSE6; Relative Productivities NMFRRU = .5 NMEXTR = 2 | |
| 0 | 11.98 |
| 1 | 14.32 |
| 2 | 17.12 |
| 3 | 20.15 |
| 4 | 22.81 |
| 5 | 23.98 |
| 6 | 24.12 |
| 7 | 23.85 |
| 8 | 23.58 |
| 9 | 23.42 |
| 10 | 23.36 |
| Model = REUSE6; Relative Productivities NMFRRU = .25 NMEXTR = 2 | |
| 0 | 11.98 |
| 1 | 14.46 |
| 2 | 17.23 |
| 3 | 20.31 |
| 4 | 23.02 |
| 5 | 24.10 |
| 6 | 24.11 |
| 7 | 23.78 |
| 8 | 23.50 |
| 9 | 23.35 |
| 10 | 23.30 |
| Model = REUSE6; Relative Productivities NMFRRU = .1 NMEXTR = 2 | |
| 0 | 11.98 |
| 1 | 14.55 |
| 2 | 17.31 |
| 3 | 20.42 |
| 4 | 23.15 |
| 5 | 24.17 |
| 6 | 24.10 |
| 7 | 23.74 |
| 8 | 23.45 |
| 9 | 23.30 |
| 10 | 23.26 |

***Table C1: Dynamica Reuse Model Tabular Data for Figure 6***

| Years | REUSE |
|---|---|
| Model = REUSE6; Relative Productivities NMFRRU = .5 NMEXTR = 4 | |
| 0 | 11.98 |
| 1 | 11.57 |
| 2 | 11.51 |
| 3 | 11.55 |
| 4 | 11.54 |
| 5 | 11.47 |
| 6 | 11.36 |
| 7 | 11.22 |
| 8 | 11.07 |
| 9 | 10.89 |
| 10 | 10.69 |
| Model = REUSE6; Relative Productivities NMFRRU = .25 NMEXTR = 4 | |
| 0 | 11.98 |
| 1 | 11.63 |
| 2 | 11.52 |
| 3 | 11.56 |
| 4 | 11.58 |
| 5 | 11.51 |
| 6 | 11.39 |
| 7 | 11.26 |
| 8 | 11.11 |
| 9 | 10.93 |
| 10 | 10.73 |
| Model = REUSE6; Relative Productivities NMFRRU = .1 NMEXTR = 4 | |
| 0 | 11.98 |
| 1 | 11.63 |
| 2 | 11.52 |
| 3 | 11.56 |
| 4 | 11.58 |
| 5 | 11.51 |
| 6 | 11.39 |
| 7 | 11.26 |
| 8 | 11.11 |
| 9 | 10.93 |
| 10 | 10.73 |

***Table C2: Dynamica Reuse Model Tabular Data for Figure 6***

Model = REUSE6; Relative Productivities NMFRRU = .25

| Years | REUSE | RPSTRY |
|---|---|---|
| 0 | 11.98 | 2,000.00 |
| 1 | 14.46 | 2,442.44 |
| 2 | 17.23 | 2,922.02 |
| 3 | 20.31 | 3,402.43 |
| 4 | 23.02 | 3,808.60 |
| 5 | 24.10 | 3,957.19 |
| 6 | 24.11 | 3,956.09 |
| 7 | 23.78 | 3,913.25 |
| 8 | 23.50 | 3,883.59 |
| 9 | 23.35 | 3,868.97 |
| 10 | 23.30 | 3,864.04 |

Model = REUSE6; Relative Productivities NMFRRU = 1

| Years | REUSE | RPSTRY |
|---|---|---|
| 0 | 8.39 | 2,000.00 |
| 1 | 10.24 | 2,361.78 |
| 2 | 10.93 | 2,744.35 |
| 3 | 12.49 | 3,116.48 |
| 4 | 14.96 | 3,444.25 |
| 5 | 17.64 | 3,718.28 |
| 6 | 20.02 | 3,867.17 |
| 7 | 21.13 | 3,905.05 |
| 8 | 21.34 | 3,896.60 |
| 9 | 21.32 | 3,884.86 |
| 10 | 21.22 | 3,873.86 |

***Table C3: Dynamica Reuse Model Tabular Data for Figure 7***

Model = REUSE6; Relative Productivities NMEXTR = 2

| Years | REUSE | RPSTRY |
|---|---|---|
| 0 | 11.98 | 2,000.00 |
| 1 | 14.46 | 2,442.44 |
| 2 | 17.23 | 2,922.02 |
| 3 | 20.31 | 3,402.43 |
| 4 | 23.02 | 3,808.60 |
| 5 | 24.10 | 3,957.19 |
| 6 | 24.11 | 3,956.09 |
| 7 | 23.78 | 3,913.25 |
| 8 | 23.50 | 3,883.59 |
| 9 | 23.35 | 3,868.97 |
| 10 | 23.30 | 3,864.04 |

Model = REUSE6; Relative Productivities NMEXTR = 4

| Years | REUSE | RPSTRY |
|---|---|---|
| 0 | 11.98 | 2,000.00 |
| 1 | 11.63 | 1,973.68 |
| 2 | 11.52 | 1,967.77 |
| 3 | 11.56 | 1,971.66 |
| 4 | 11.58 | 1,971.59 |
| 5 | 11.51 | 1,962.74 |
| 6 | 11.39 | 1,947.34 |
| 7 | 11.26 | 1,926.91 |
| 8 | 11.11 | 1,901.70 |
| 9 | 10.93 | 1,872.19 |
| 10 | 10.73 | 1,839.35 |

***Table C4: Dynamica Reuse Model Tabular Data for Figure 8***

# APPENDIX D: EMPLOYEE TURNOVER DOCUMENTATION

Model = REUSE6; Employee Turnover AVEMPT = 21

| Years | FREXP | REUSE |
|---|---|---|
| 0 | 0.85 | 11.98 |
| 1 | 0.75 | 12.98 |
| 2 | 0.74 | 15.06 |
| 3 | 0.76 | 17.69 |
| 4 | 0.77 | 19.64 |
| 5 | 0.77 | 20.50 |
| 6 | 0.77 | 20.81 |
| 7 | 0.77 | 20.94 |
| 8 | 0.78 | 20.93 |
| 9 | 0.78 | 20.86 |
| 10 | 0.77 | 20.83 |

Model = REUSE6; Employee Turnover AVEMPT = 42

| Years | FREXP | REUSE |
|---|---|---|
| 0 | 0.85 | 11.98 |
| 1 | 0.85 | 14.46 |
| 2 | 0.85 | 17.23 |
| 3 | 0.86 | 20.31 |
| 4 | 0.87 | 23.02 |
| 5 | 0.87 | 24.10 |
| 6 | 0.87 | 24.11 |
| 7 | 0.87 | 23.78 |
| 8 | 0.87 | 23.50 |
| 9 | 0.87 | 23.35 |
| 10 | 0.87 | 23.30 |

***Table D1: Dynamica Reuse Model Tabular Data for Figure 9***

Model = REUSE6; Employee Turnover AVEMPT = 21

| Years | FREXP | ADJRCP |
|---|---|---|
| 0 | 0.85 | 7.29 |
| 1 | 0.75 | 8.38 |
| 2 | 0.74 | 8.92 |
| 3 | 0.76 | 9.37 |
| 4 | 0.77 | 8.31 |
| 5 | 0.77 | 7.43 |
| 6 | 0.77 | 7.01 |
| 7 | 0.77 | 6.88 |
| 8 | 0.78 | 6.87 |
| 9 | 0.78 | 6.89 |
| 10 | 0.77 | 6.90 |

Model = REUSE6; Employee Turnover AVEMPT = 42

| Years | FREXP | ADJRCP |
|---|---|---|
| 0 | 0.85 | 7.29 |
| 1 | 0.85 | 8.57 |
| 2 | 0.85 | 9.22 |
| 3 | 0.86 | 9.65 |
| 4 | 0.87 | 8.63 |
| 5 | 0.87 | 7.02 |
| 6 | 0.87 | 6.45 |
| 7 | 0.87 | 6.56 |
| 8 | 0.87 | 6.70 |
| 9 | 0.87 | 6.77 |
| 10 | 0.87 | 6.80 |

***Table D2: Dynamica Reuse Model Tabular Data for Figure 10***

Model = REUSE6; Employee Turnover PHGHWF = 0

| YEARS | REUSE | TOTWF |
|---|---|---|
| 0 | 11.98 | 2,000.00 |
| 1 | 14.46 | 2,087.33 |
| 2 | 17.23 | 2,268.56 |
| 3 | 20.31 | 2,392.11 |
| 4 | 23.02 | 2,456.67 |
| 5 | 24.10 | 2,493.77 |
| 6 | 24.11 | 2,518.20 |
| 7 | 23.78 | 2,527.81 |
| 8 | 23.50 | 2,541.46 |
| 9 | 23.35 | 2,564.34 |
| 10 | 23.30 | 2,588.34 |

Model = REUSE6; Employee Turnover PHGHWF = .25

| YEARS | REUSE | TOTWF |
|---|---|---|
| 0 | 11.98 | 2,000.00 |
| 1 | 14.46 | 2,087.33 |
| 2 | 17.23 | 2,268.56 |
| 3 | 20.31 | 2,392.11 |
| 4 | 23.02 | 2,456.67 |
| 5 | 24.10 | 2,493.77 |
| 6 | 22.09 | 2,781.37 |
| 7 | 23.88 | 2,671.40 |
| 8 | 23.78 | 2,460.82 |
| 9 | 23.09 | 2,493.36 |
| 10 | 23.07 | 2,618.40 |

***Table D3: Dynamica Reuse Model Tabular Data for Figure 11***

Model = REUSE6; Employee Turnover PHGHWF = 0

| YEARS | REUSE |
|---|---|
| 0 | 11.98 |
| 1 | 14.46 |
| 2 | 17.23 |
| 3 | 20.31 |
| 4 | 23.02 |
| 5 | 24.10 |
| 6 | 24.11 |
| 7 | 23.78 |
| 8 | 23.50 |
| 9 | 23.35 |
| 10 | 23.30 |

Model = REUSE6; Employee Turnover PHGHWF = .25

| YEARS | REUSE |
|---|---|
| 0 | 11.98 |
| 1 | 14.46 |
| 2 | 17.23 |
| 3 | 20.31 |
| 4 | 23.02 |
| 5 | 24.10 |
| 6 | 22.09 |
| 7 | 23.88 |
| 8 | 23.78 |
| 9 | 23.09 |
| 10 | 23.07 |

***Table D4: Dynamica Reuse Model Tabular Data for Figure 12***

# APPENDIX E: REPOSITORY SIZE DOCUMENTATION

Model = REUSE6; Repository: Nominal Case

| Years | REUSE | ADJRCP | RPSTRY |
|---|---|---|---|
| 0 | 11.98 | 7.29 | 2,000.00 |
| 1 | 14.46 | 8.57 | 2,442.44 |
| 2 | 17.23 | 9.22 | 2,922.02 |
| 3 | 20.31 | 9.65 | 3,402.43 |
| 4 | 23.02 | 8.63 | 3,808.60 |
| 5 | 24.10 | 7.02 | 3,957.19 |
| 6 | 24.11 | 6.45 | 3,956.09 |
| 7 | 23.78 | 6.56 | 3,913.25 |
| 8 | 23.50 | 6.70 | 3,883.59 |
| 9 | 23.35 | 6.77 | 3,868.97 |
| 10 | 23.30 | 6.80 | 3,864.04 |
| 11 | 23.30 | 6.81 | 3,862.95 |
| 12 | 23.29 | 6.81 | 3,862.57 |
| 13 | 23.28 | 6.81 | 3,862.19 |
| 14 | 23.28 | 6.81 | 3,861.91 |
| 15 | 23.27 | 6.81 | 3,861.60 |
| 16 | 23.26 | 6.81 | 3,861.16 |
| 17 | 23.25 | 6.82 | 3,860.62 |
| 18 | 23.24 | 6.82 | 3,860.09 |
| 19 | 23.24 | 6.82 | 3,859.62 |
| 20 | 23.23 | 6.82 | 3,859.18 |
| 21 | 23.22 | 6.82 | 3,858.73 |
| 22 | 23.22 | 6.82 | 3,858.30 |
| 23 | 23.21 | 6.82 | 3,857.89 |
| 24 | 23.20 | 6.83 | 3,857.51 |
| 25 | 23.20 | 6.83 | 3,857.14 |
| 26 | 23.19 | 6.83 | 3,856.79 |
| 27 | 23.19 | 6.83 | 3,856.46 |
| 28 | 23.18 | 6.83 | 3,856.16 |
| 29 | 23.18 | 6.83 | 3,855.87 |
| 30 | 23.18 | 6.83 | 3,855.60 |

***Table E1: Dynamica Reuse Model Tabular Data for Figure 13***

Model = REUSE6; Repository: PHGHRP= +.25

| Years | REUSE | ADJRCP | RPSTRY |
|---|---|---|---|
| 0 | 11.98 | 7.29 | 2,000.00 |
| 1 | 14.46 | 8.57 | 2,442.44 |
| 2 | 17.23 | 9.22 | 2,922.02 |
| 3 | 20.31 | 9.65 | 3,402.43 |
| 4 | 23.02 | 8.63 | 3,808.60 |
| 5 | 24.10 | 7.02 | 3,957.19 |
| 6 | 26.69 | 3.76 | 4,356.21 |
| 7 | 24.76 | 5.49 | 4,064.02 |
| 8 | 23.91 | 6.36 | 3,928.31 |
| 9 | 23.33 | 6.43 | 3,859.33 |
| 10 | 22.70 | 5.93 | 3,776.05 |
| 11 | 22.11 | 5.60 | 3,679.10 |
| 12 | 21.52 | 5.46 | 3,577.28 |
| 13 | 20.89 | 5.34 | 3,477.98 |
| 14 | 20.30 | 5.37 | 3,390.11 |
| 15 | 19.88 | 5.47 | 3,327.03 |
| 16 | 19.64 | 5.61 | 3,289.63 |
| 17 | 19.54 | 5.75 | 3,275.62 |
| 18 | 19.54 | 5.83 | 3,276.24 |
| 19 | 19.60 | 5.92 | 3,287.24 |
| 20 | 19.72 | 6.00 | 3,305.86 |
| 21 | 19.86 | 6.07 | 3,329.26 |
| 22 | 20.02 | 6.14 | 3,355.14 |
| 23 | 20.18 | 6.19 | 3,381.72 |
| 24 | 20.34 | 6.23 | 3,407.74 |
| 25 | 20.49 | 6.26 | 3,432.33 |
| 26 | 20.63 | 6.29 | 3,454.93 |
| 27 | 20.76 | 6.31 | 3,475.22 |
| 28 | 20.87 | 6.32 | 3,493.07 |
| 29 | 20.97 | 6.33 | 3,508.47 |
| 30 | 21.05 | 6.34 | 3,521.55 |

***Table E2: Dynamica Reuse Model Tabular Data for Figure 14***

Model = REUSE6; Repository: PHGHRP= -.25

| Years | REUSE | ADJRCP | RPSTRY |
|---|---|---|---|
| 0 | 11.98 | 7.29 | 2,000.00 |
| 1 | 14.46 | 8.57 | 2,442.44 |
| 2 | 17.23 | 9.22 | 2,922.02 |
| 3 | 20.31 | 9.65 | 3,402.43 |
| 4 | 23.02 | 8.63 | 3,808.60 |
| 5 | 24.10 | 7.02 | 3,957.19 |
| 6 | 20.85 | 9.93 | 3,438.16 |
| 7 | 22.65 | 8.17 | 3,755.90 |
| 8 | 23.31 | 6.98 | 3,871.36 |
| 9 | 23.55 | 6.69 | 3,893.61 |
| 10 | 23.57 | 6.71 | 3,887.75 |
| 11 | 23.43 | 6.76 | 3,874.71 |
| 12 | 23.31 | 6.79 | 3,866.12 |
| 13 | 23.27 | 6.80 | 3,863.45 |
| 14 | 23.28 | 6.80 | 3,862.86 |
| 15 | 23.27 | 6.81 | 3,862.00 |
| 16 | 23.26 | 6.81 | 3,861.10 |
| 17 | 23.25 | 6.81 | 3,860.65 |
| 18 | 23.24 | 6.81 | 3,860.38 |
| 19 | 23.24 | 6.82 | 3,859.93 |
| 20 | 23.23 | 6.82 | 3,859.35 |
| 21 | 23.22 | 6.82 | 3,858.83 |
| 22 | 23.22 | 6.82 | 3,858.41 |
| 23 | 23.21 | 6.82 | 3,858.00 |
| 24 | 23.20 | 6.82 | 3,857.59 |
| 25 | 23.20 | 6.83 | 3,857.19 |
| 26 | 23.19 | 6.83 | 3,856.83 |
| 27 | 23.19 | 6.83 | 3,856.50 |
| 28 | 23.18 | 6.83 | 3,856.18 |
| 29 | 23.18 | 6.83 | 3,855.88 |
| 30 | 23.18 | 6.83 | 3,855.60 |

***Table E3: Dynamica Reuse Model Tabular Data for Figure 15***

Model = REUSE6; Repository: PHGHRP= +.50

| Years | REUSE | ADJRCP | RPSTRY |
|---|---|---|---|
| 0 | 11.98 | 7.29 | 2,000.00 |
| 1 | 14.46 | 8.57 | 2,442.44 |
| 2 | 17.23 | 9.22 | 2,922.02 |
| 3 | 20.31 | 9.65 | 3,402.43 |
| 4 | 23.02 | 8.63 | 3,808.60 |
| 5 | 24.10 | 7.02 | 3,957.19 |
| 6 | 28.86 | 1.48 | 5,029.74 |
| 7 | 26.75 | 3.54 | 4,374.00 |
| 8 | 24.92 | 5.55 | 4,051.19 |
| 9 | 23.64 | 6.11 | 3,885.79 |
| 10 | 22.17 | 4.74 | 3,695.89 |
| 11 | 20.75 | 4.18 | 3,471.06 |
| 12 | 19.50 | 4.00 | 3,255.40 |
| 13 | 18.35 | 4.16 | 3,068.31 |
| 14 | 17.61 | 4.86 | 2,962.43 |
| 15 | 17.48 | 5.52 | 2,953.40 |
| 16 | 17.78 | 5.89 | 3,003.18 |
| 17 | 18.33 | 6.18 | 3,088.65 |
| 18 | 18.91 | 6.28 | 3,178.50 |
| 19 | 19.43 | 6.35 | 3,261.07 |
| 20 | 19.88 | 6.39 | 3,332.66 |
| 21 | 20.25 | 6.40 | 3,392.00 |
| 22 | 20.55 | 6.42 | 3,439.83 |
| 23 | 20.79 | 6.43 | 3,478.37 |
| 24 | 20.98 | 6.44 | 3,509.42 |
| 25 | 21.13 | 6.44 | 3,534.32 |
| 26 | 21.26 | 6.44 | 3,554.14 |
| 27 | 21.35 | 6.44 | 3,569.88 |
| 28 | 21.43 | 6.45 | 3,582.41 |
| 29 | 21.49 | 6.45 | 3,592.45 |
| 30 | 21.54 | 6.45 | 3,600.50 |

***Table E4: Dynamica Reuse Model Tabular Data for Figure 16***

Model = REUSE6; Repository: PHGHRP= -.50

| Years | REUSE | ADJRCP | RPSTRY |
|---|---|---|---|
| 0 | 11.98 | 7.29 | 2,000.00 |
| 1 | 14.46 | 8.57 | 2,442.44 |
| 2 | 17.23 | 9.22 | 2,922.02 |
| 3 | 20.31 | 9.65 | 3,402.43 |
| 4 | 23.02 | 8.63 | 3,808.60 |
| 5 | 24.10 | 7.02 | 3,957.19 |
| 6 | 15.91 | 10.68 | 2,633.60 |
| 7 | 19.07 | 10.32 | 3,193.00 |
| 8 | 21.70 | 9.01 | 3,664.72 |
| 9 | 23.46 | 7.28 | 3,899.66 |
| 10 | 24.09 | 6.60 | 3,950.02 |
| 11 | 23.85 | 6.57 | 3,915.52 |
| 12 | 23.46 | 6.70 | 3,882.54 |
| 13 | 23.28 | 6.76 | 3,867.53 |
| 14 | 23.26 | 6.79 | 3,863.31 |
| 15 | 23.26 | 6.81 | 3,861.65 |
| 16 | 23.25 | 6.81 | 3,860.42 |
| 17 | 23.24 | 6.82 | 3,859.98 |
| 18 | 23.23 | 6.81 | 3,860.02 |
| 19 | 23.23 | 6.82 | 3,859.82 |
| 20 | 23.23 | 6.82 | 3,859.27 |
| 21 | 23.22 | 6.82 | 3,858.70 |
| 22 | 23.21 | 6.82 | 3,858.27 |
| 23 | 23.21 | 6.82 | 3,857.90 |
| 24 | 23.20 | 6.83 | 3,857.50 |
| 25 | 23.20 | 6.83 | 3,857.10 |
| 26 | 23.19 | 6.83 | 3,856.73 |
| 27 | 23.19 | 6.83 | 3,856.41 |
| 28 | 23.18 | 6.83 | 3,856.11 |
| 29 | 23.18 | 6.83 | 3,855.81 |
| 30 | 23.18 | 6.83 | 3,855.53 |

***Table E5: Dynamica Reuse Model Tabular Data for Figure 17***

Model = REUSE6; Repository: PHGHRP= +.75

| Years | REUSE | ADJRCP | RPSTRY |
|---|---|---|---|
| 0 | 11.98 | 7.29 | 2,000.00 |
| 1 | 14.46 | 8.57 | 2,442.44 |
| 2 | 17.23 | 9.22 | 2,922.02 |
| 3 | 20.31 | 9.65 | 3,402.43 |
| 4 | 23.02 | 8.63 | 3,808.60 |
| 5 | 24.10 | 7.02 | 3,957.19 |
| 6 | 28.62 | 1.46 | 5,819.33 |
| 7 | 28.69 | 1.69 | 4,893.39 |
| 8 | 26.62 | 4.06 | 4,291.54 |
| 9 | 24.46 | 5.91 | 3,982.69 |
| 10 | 22.46 | 4.37 | 3,738.95 |
| 11 | 20.52 | 3.56 | 3,445.22 |
| 12 | 18.90 | 3.28 | 3,162.88 |
| 13 | 17.46 | 3.64 | 2,921.61 |
| 14 | 16.66 | 4.81 | 2,808.83 |
| 15 | 16.67 | 5.55 | 2,828.05 |
| 16 | 17.21 | 5.99 | 2,915.64 |
| 17 | 17.92 | 6.17 | 3,023.98 |
| 18 | 18.61 | 6.31 | 3,130.24 |
| 19 | 19.21 | 6.38 | 3,225.75 |
| 20 | 19.71 | 6.41 | 3,307.27 |
| 21 | 20.13 | 6.42 | 3,374.02 |
| 22 | 20.47 | 6.44 | 3,427.48 |
| 23 | 20.73 | 6.45 | 3,470.25 |
| 24 | 20.95 | 6.46 | 3,504.66 |
| 25 | 21.12 | 6.46 | 3,532.31 |
| 26 | 21.26 | 6.46 | 3,554.37 |
| 27 | 21.37 | 6.46 | 3,571.91 |
| 28 | 21.45 | 6.47 | 3,585.93 |
| 29 | 21.52 | 6.47 | 3,597.20 |
| 30 | 21.58 | 6.47 | 3,606.30 |

***Table E6: Dynamica Reuse Model Tabular Data for Figure 18***

Model = REUSE6; Repository: PHGHRP= -.75

| Years | REUSE | ADJRCP | RPSTRY |
|---|---|---|---|
| 0 | 11.98 | 7.29 | 2,000.00 |
| 1 | 14.46 | 8.57 | 2,442.44 |
| 2 | 17.23 | 9.22 | 2,922.02 |
| 3 | 20.31 | 9.65 | 3,402.43 |
| 4 | 23.02 | 8.63 | 3,808.60 |
| 5 | 24.10 | 7.02 | 3,957.19 |
| 6 | 11.41 | 13.24 | 1,914.22 |
| 7 | 16.73 | 12.27 | 2,816.39 |
| 8 | 21.13 | 10.70 | 3,575.83 |
| 9 | 23.72 | 7.59 | 3,947.74 |
| 10 | 24.55 | 6.53 | 4,017.17 |
| 11 | 24.20 | 6.32 | 3,960.78 |
| 12 | 23.63 | 6.59 | 3,902.21 |
| 13 | 23.33 | 6.72 | 3,873.77 |
| 14 | 23.26 | 6.78 | 3,864.18 |
| 15 | 23.26 | 6.81 | 3,861.10 |
| 16 | 23.24 | 6.82 | 3,859.76 |
| 17 | 23.23 | 6.82 | 3,859.62 |
| 18 | 23.23 | 6.81 | 3,860.07 |
| 19 | 23.23 | 6.81 | 3,860.03 |
| 20 | 23.23 | 6.82 | 3,859.41 |
| 21 | 23.22 | 6.82 | 3,858.75 |
| 22 | 23.21 | 6.82 | 3,858.31 |
| 23 | 23.21 | 6.82 | 3,857.95 |
| 24 | 23.20 | 6.82 | 3,857.55 |
| 25 | 23.20 | 6.83 | 3,857.13 |
| 26 | 23.19 | 6.83 | 3,856.76 |
| 27 | 23.19 | 6.83 | 3,856.43 |
| 28 | 23.18 | 6.83 | 3,856.13 |
| 29 | 23.18 | 6.83 | 3,855.83 |
| 30 | 23.18 | 6.83 | 3,855.54 |

***Table E7: Dynamica Reuse Model Tabular Data for Figure 19***

# APPENDIX F: SOFTWARE DEVELOPMENT RATE DOCUMENTATION

Model = REUSE6; Software Development Rate NMGRW1 = 0, NMGRW4 = 0

| Years | REUSE | SWDVRT |
|---|---|---|
| 0 | 11.98 | 968.46 |
| 1 | 14.46 | 973.41 |
| 2 | 17.23 | 1,002.57 |
| 3 | 20.31 | 1,010.16 |
| 4 | 23.02 | 1,017.50 |
| 5 | 24.10 | 1,005.18 |
| 6 | 24.11 | 972.67 |
| 7 | 23.78 | 946.59 |
| 8 | 23.50 | 939.59 |
| 9 | 23.35 | 941.83 |
| 10 | 23.30 | 944.52 |

***Table F1: Dynamica Reuse Model Tabular Data for Figure 20***

Model = REUSE6; Software Development Rate NMGRW1 = 1, NMGRW4 = 0

| Years | REUSE | SWDVRT |
|---|---|---|
| 0 | 11.98 | 968.46 |
| 1 | 14.43 | 998.89 |
| 2 | 17.43 | 1,118.50 |
| 3 | 21.42 | 1,255.64 |
| 4 | 24.45 | 1,410.34 |
| 5 | 25.45 | 1,471.34 |
| 6 | 25.66 | 1,535.66 |
| 7 | 25.80 | 1,630.89 |
| 8 | 26.01 | 1,740.26 |
| 9 | 26.22 | 1,859.15 |
| 10 | 26.41 | 1,989.07 |

***Table F2: Dynamica Reuse Model Tabular Data for Figure 21***

Model = REUSE6; Software Development Rate NMGRW1 = 0, NMGRW4 = 1

| Years | REUSE | SWDVRT |
|---|---|---|
| 0 | 11.98 | 968.46 |
| 1 | 14.39 | 1,033.58 |
| 2 | 17.77 | 1,185.09 |
| 3 | 22.32 | 1,127.74 |
| 4 | 28.07 | 951.71 |
| 5 | 25.30 | 793.55 |
| 6 | 21.20 | 932.99 |
| 7 | 22.54 | 1,143.02 |
| 8 | 24.27 | 1,047.30 |
| 9 | 27.34 | 840.41 |
| 10 | 24.26 | 749.63 |

***Table F3: Dynamica Reuse Model Tabular Data for Figure 22***

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